The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association

OCTOBER 1957

American Volume
Vol. 39-A, No. 5

8 THE FENWAY, BOSTON 15, MASSACHUSETTS, U. S. A.
BRITISH OFFICE:
82 PORTLAND PLACE, LONDON, W. 1, ENGLAND

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The Journal of Bone and Joint Surgery (American Volume) is issued six times a year—in January, April, June, July, October, and December. The 1957 subscription price, payable in advance, is $13.00. Single copies $2.50.

The Journal of Bone and Joint Surgery, second-class mail privileges authorized at Boston, Mass. Editorial and business offices, 8 The Fenway, Boston, Mass. Accepted at the special rate of postage provided for in the act of February 28, 1925. Paragraph 4, Section 412, Postal Laws and Regulations; authorized April 21, 1932. Additional entry at Concord, New Hampshire, authorized June 10, 1947.

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AMERICAN AND BRITISH VOLUMES — Combination price $20.00

American Volume, $13.00
Published January, April, June, July, October, December

British Volume, $10.00
Published February, May, August, November

All subscription rates include postage.

Checks should be made payable to *The Journal of Bone and Joint Surgery, Inc.*

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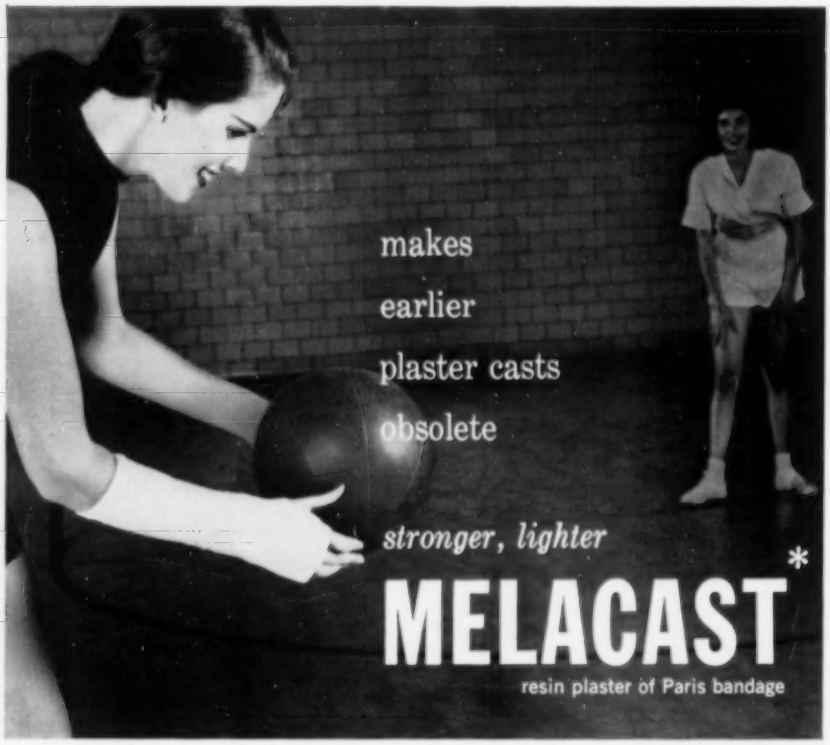

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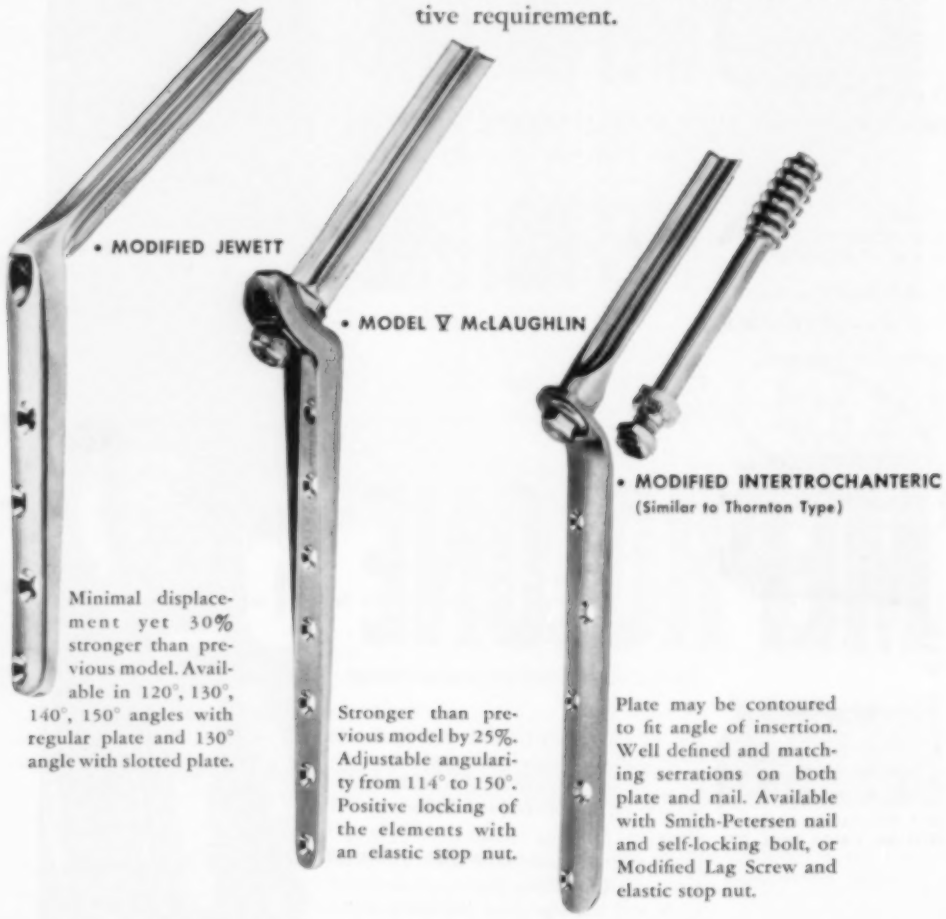

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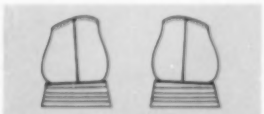

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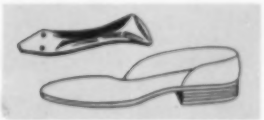

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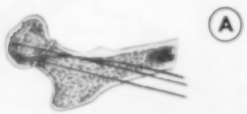
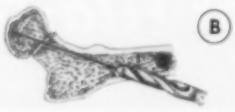


6 A trial film indicates the guide wire of choice to lie on the medial trabeculations in AP film or slightly posterior to midline in lateral film, and a ½" hole is reamed along this wire with a ½" reamer.



7 With the nail fully extended with the inserte in place, the nail and barrel are easily inserte so that the nail approaches the cortex of th proximal fragment. An x-ray is taken.

The plate is thrust distally under the vastu lateralis, then slipped into place over the groove of the end of the barrel.

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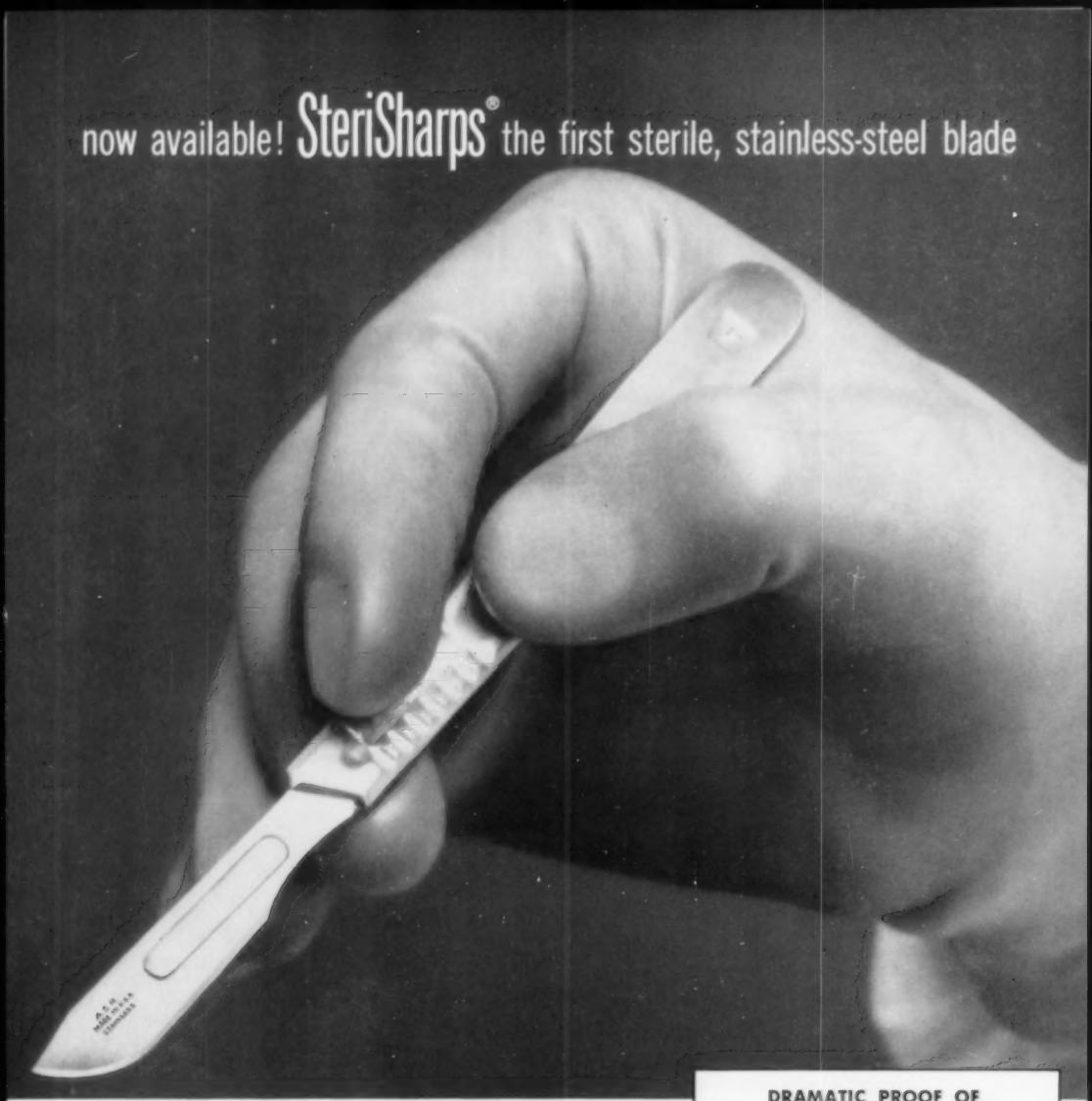

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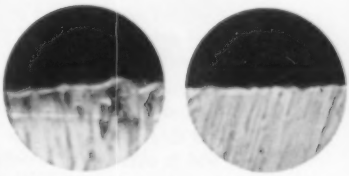

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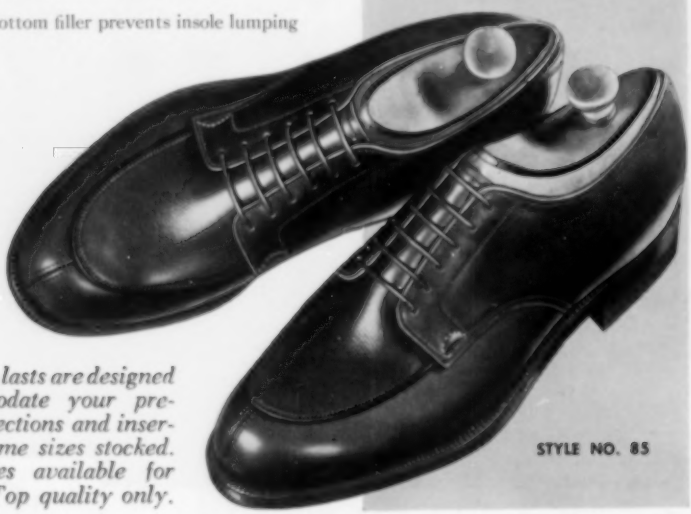

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". . . Disipal is an orally effective and safe antispasmodic drug. Results are prompt, and gratifying to the patient. The number of office visits . . . is reduced significantly. The dosage schedule is simple, and side actions are minimal . . ."

Finch, J.W.: Clinical Trial of Orphenadrine (Disipal) in Skeletal Muscle Disorders. To be published.

Disipal®*

Brand of Orphenadrine HCl

ADVANTAGES

- Speedy relief of muscle spasm
- Orally effective
- Relatively long-acting
- Minimal side actions
- Mildly euphoric
- Nonsoporific
- Tolerance no problem
- No known organic contra-indications
- Economical

INDICATIONS

Parkinsonism

•

Muscle spasm due to

- Sprains
- Strains
- Herniated intervertebral disc
- Fibrositis
- Low back pain
- Whiplash injuries
- Noninflammatory rheumatic and arthritic states
- Torticollis

*Trademark of Brocades-Stheeman & Pharmacia, U.S. Patent No. 2,567,351. Other patents pending.

In Parkinsonism

"In a series of 176 patients . . . a valuable adjunct to therapy . . . a highly selective action . . . that cannot be duplicated by any other current remedy . . . effective as a euphoriant . . . and as an energizing agent against weakness, fatigue, adynamia, and akinesia . . . potent action against sialorrhea, diaphoresis, oculogyria, and blepharospasm . . . also lessens rigidity and tremor . . . harmless . . . minimal side-reactions . . . safe . . . even in cases complicated by glaucoma."

Doshay, L.J., and Constable, K.: Treatment of Paralysis Agitans with Orphenadrine (Disipal) Hydrochloride: Results in One Hundred Seventy-Six Cases, J.A.M.A. *163*:1352 (Apr. 13) 1957.

Dosage: 1 tablet (50 mg.) t.i.d. In Parkinsonism, when used in combination with other drugs, smaller dosage may suffice.

Riker
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In answering advertisements, please mention *The Journal of Bone and Joint Surgery*.

Stryker

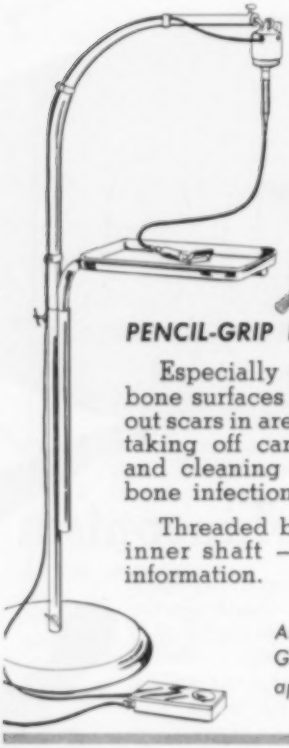
ELECTRO-SURGICAL UNIT

Effective • Safe • Efficient

The Stryker Electro Surgical Unit is becoming standard hospital equipment to accommodate the increasing use of attachable surgical instruments.

The speed and power of the enclosed motor is controlled by the new explosion proof foot switch. The motor may be suspended from an IV stand or from the standard shown below. Each interchangeable instrument is light, sensitive and powered thru a single flexible cable. This variety of tools at the surgeon's finger tips allows versatility and adds artistry to his surgical skill.

Complete unit fits conveniently in a single foam rubber lined carrying case.



3/8" diameter

PENCIL-GRIP ROTARY HANDPIECE

Especially useful for freshening bone surfaces for grafting, cleaning out scars in areas of pseudoarthrosis, taking off cartilage in arthrodesis and cleaning out areas of chronic bone infection.

Threaded burs are screwed into inner shaft — write for bur size information.

Ask for the Stryker Pencil-Grip Rotary Handpiece on approval — write today.

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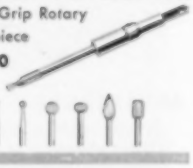
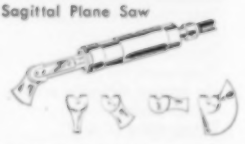
$90.00

Rolo-Dermatome
$148.00

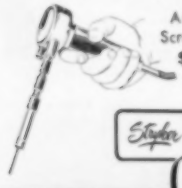
Pencil-Grip Rotary Handpiece
$75.00



Sagittal Plane Saw



The Bone Drill Handpiece Operates each of these tools:



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$24.50

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$110.00

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$28.00

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New Curity adhesive is easy to handle

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. . . and easy on patients too: Easy to remove. Comes off clean, with no sticky mass left on skin. Kind to skin—you can't put a less irritating adhesive on a patient.

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HIP PROSTHESIS UNITS

These new units embody important improvements for many times greater strength, yet the popular basic design is unchanged. Fins on stem have serrated edges to assure firm implanting. Stem is available in large and medium size. Design permits keeping maximum of cortical bone in neck for greater weight bearing surface. Radius of special Broach is same as stem. Little broaching is necessary and prosthesis is easier to insert and seat. Collar on stem enables weight to bear on femoral neck. In Three Piece Unit ball portion, or head, and washer are detachable from stem, or nail. Different sizes of femoral heads can be fiitted without removing entire unit. Ball portion hollowed out to allow movement of the ball even after it has become frozen in the socket. Can be used with or without removable washer, which provides greater length if needed. Complete set, No. 618A. One Piece Unit, No. 633, available for those who prefer this type. Each unit is X-Ray tested to guard against internal defects, Zyglo-Pentrex tested against external defects, and each unit is numbered and catalogued for reference. In addition, actual strength tests are performed to insure design strength. When ordering, be sure to specify whether large or medium stem and diameter of ball (1⅝", 1¾", 1⅞" or 2").

BROACH, No. 663, specially designed four-flange type for use with these units.

DRIVER, No. 563, for Three Piece Unit; No. 638 for One Piece Unit.

16MM COLOR-SOUND FILM AVAILABLE for showing at medical society meetings, etc. A professional movie with three operations employing Scuderi Hip Prosthesis Units. A valuable technical aid to orthopaedists.

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recommend Edwards *Pedic Shoes*

Fifty-seven years of craftsmanship go into the making of Edwards Pedic shoes, the only complete line of children's prescription shoes in America. Ideal for lateral or medial wedging, Edwards Pedics are made on tested lasts, from clinic-approved patterns. Write for the name of your nearest Edwards dealer, who is trained in prescription fitting, and for a Pedic brochure.

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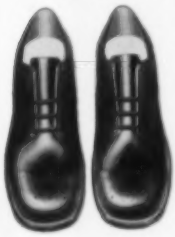

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for mild cases
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well established in

LOW BACK PAIN

and other
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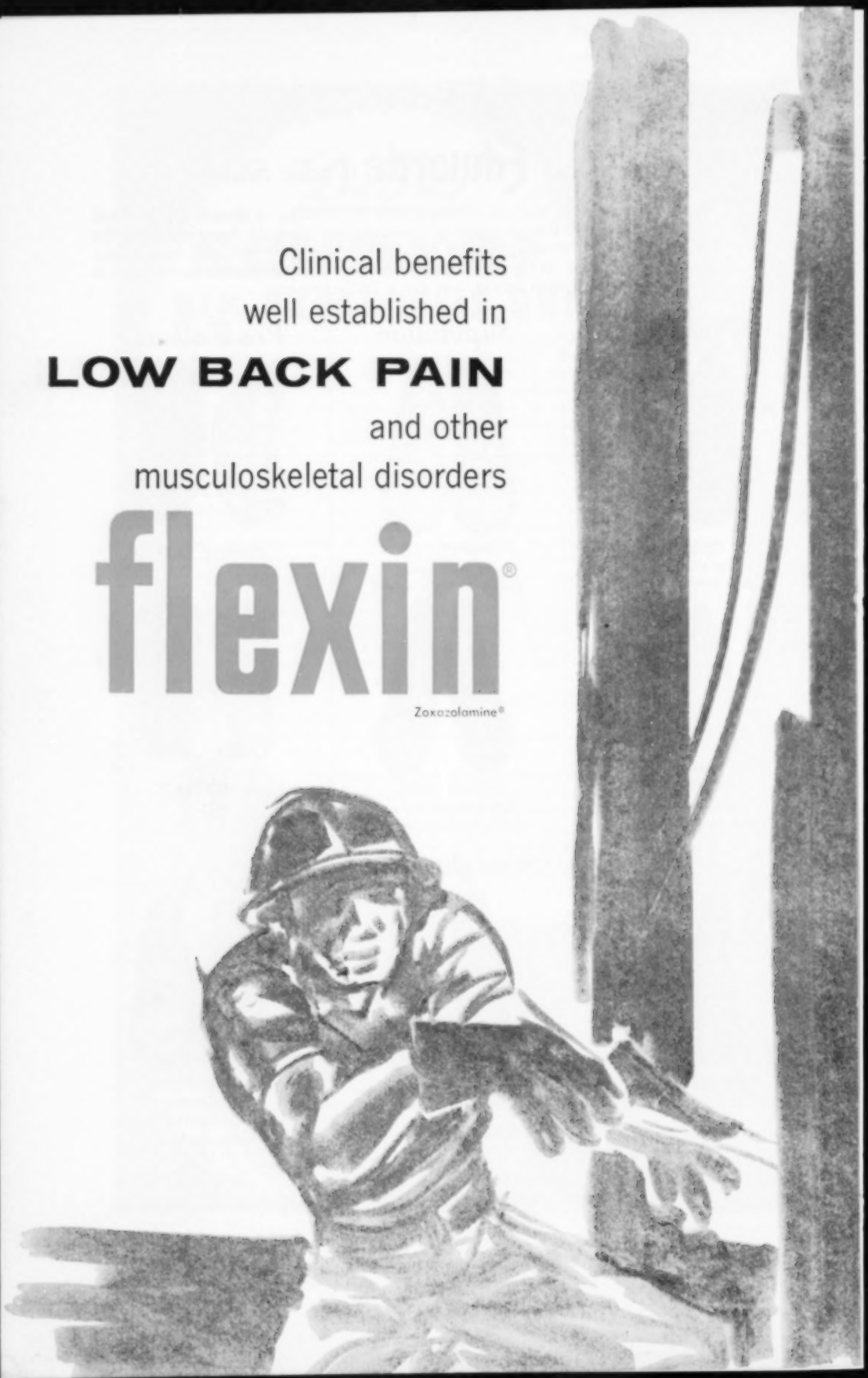

"...in the treatment of 90 patients with low back pain and other muscular conditions...67 (74 per cent) showed a good response following treatment with Flexin."[1]

"In acute and chronic recurrent low back syndrome, seven of eight patients showed visible objective improvement."[2]

"A high percentage of patients with these conditions [sprains, muscle strains and contusions, low back disorders, fibrositis, bursitis, myositis, and spondylitis] may be expected to be benefited by the drug with attending relief of muscle spasm discomfort."[3]

references (1) Johnson, H. J., Jr.: To be published. (2) Settel, E.: Am. Pract. & Digest Treat. 8:443 (March) 1957. (3) New and Nonofficial Remedies, J.A.M.A. 162:205-207 (Sept. 15) 1956.

how supplied Pink, enteric coated tablets (250 mg.), bottles of 36. Yellow, scored tablets (250 mg.), bottles of 50.

McNEIL Laboratories, Inc • Philadelphia 32, Pa.

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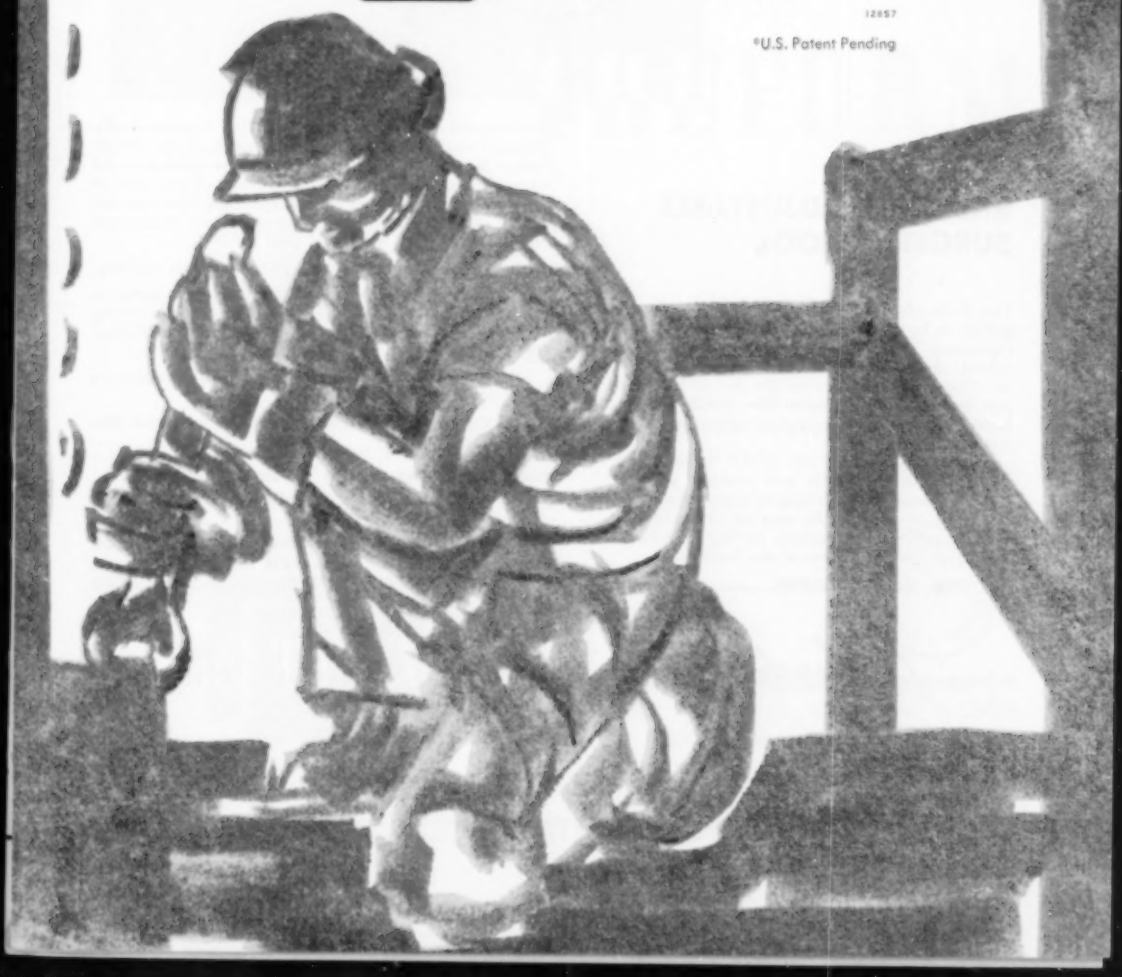
*U.S. Patent Pending



Richards

BOYES-PARKER HAND OPERATING TABLE

(U. S. PATENT NO. 2,609,251)

The surgeon and his assistant will find a scientifically designed workbench, efficient and steady, in the Boyes-Parker Hand Operating Table. It eliminates tension and strain during operations. Relieves cramped positions of the hands, arms and shoulders. Space for forearms and elbows improve operative steadiness without tiring, and can thus cut down operating time by 20%.

Removeable stainless steel pan facilitates washing.

Light in weight, easy for nurse to quickly place in position. Adjustable legs allow fitting to any operating table level. Collapsible; requires minimum of storage space.

Pull-out instrument board places instruments in ready position for use.

Formica top; all stainless steel parts; conductive rubber ends on feet.

No. 454	BOYES-PARKER HAND OPERATING TABLE (Complete with No. 454A Pan)	$160.00
No. 454A	STAINLESS PAN ONLY	16.00
No. 454B	STAINLESS STEEL PAN WITH 1/4" DRAIN PLUG	20.00

RICHARDS ADJUSTABLE SURGERY STOOL

The Richards adjustable stool is designed primarily to be used with the Boyes-Parker Hand Operating Table. Constructed of durable steel tubing, chromium plated. Three legs give stability. The stool embodies the features of an ideal seat for the hand surgeon. The saddle shaped hardwood seat is firm and comfortable, with rounded edges.

The rigid stool does not swivel; there are no casters to slide. Simple and positive up and down adjustment. By sitting on a stool that does not pivot or wobble, the surgeon can maintain an efficient, tireless posture, resting the elbows on the projecting curves of the hand table.

No. 455 SURGERY STOOL.....$55.00

Richards MANUFACTURING CO., MEMPHIS, TENN.

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THREE pull straps control traction in model 430-EHS lumbo-sacral support pictured . . . two semi-rigid steels. WRITE for "Truform Red Book," the fully illustrated reference catalog of Surgical Supports and Elastic Hosiery.

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Please read this "detail", Doctor . . .
because it's what your favorite **Truform** fitter would tell you, we believe, if he or she visited your office . . .

Truform's educational program offers the finest training in the selection and fitting of *surgical* supports. **Truform** supports are designed on well-understood physiological principles, with a thorough understanding of the supportive or corrective effects to be attained. And there are a wide variety of designs to permit your selection of exactly the correct type to provide maximum therapeutic effect consistent with comfort.

TRUFORM Anatomical Supports are available only from the Ethical Appliance Dealer.

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weeks?

months?

years?

Improve the prognosis in fractures with "Premarin" with Methyltestosterone

Healing of fractures is often delayed because impairment of osteoblastic activity due to declining sex hormone function causes the bone matrix to atrophy.

Older patients with fractures, particularly of the hip, respond well to combined estrogen-androgen therapy. The prognosis for bone recalcification is good provided treatment is continued for extended periods.*

*Reifenstein, E. C., Jr., in Harrison, T. R.: Principles of Internal Medicine, ed. 2, New York, The Blakiston Company, Inc., 1954, chap. 98, pp. 702, 703.

"PREMARIN"® with METHYLTESTOSTERONE

Excellent preparation for estrogen-androgen therapy

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—IN **NEUTRILIUM®**

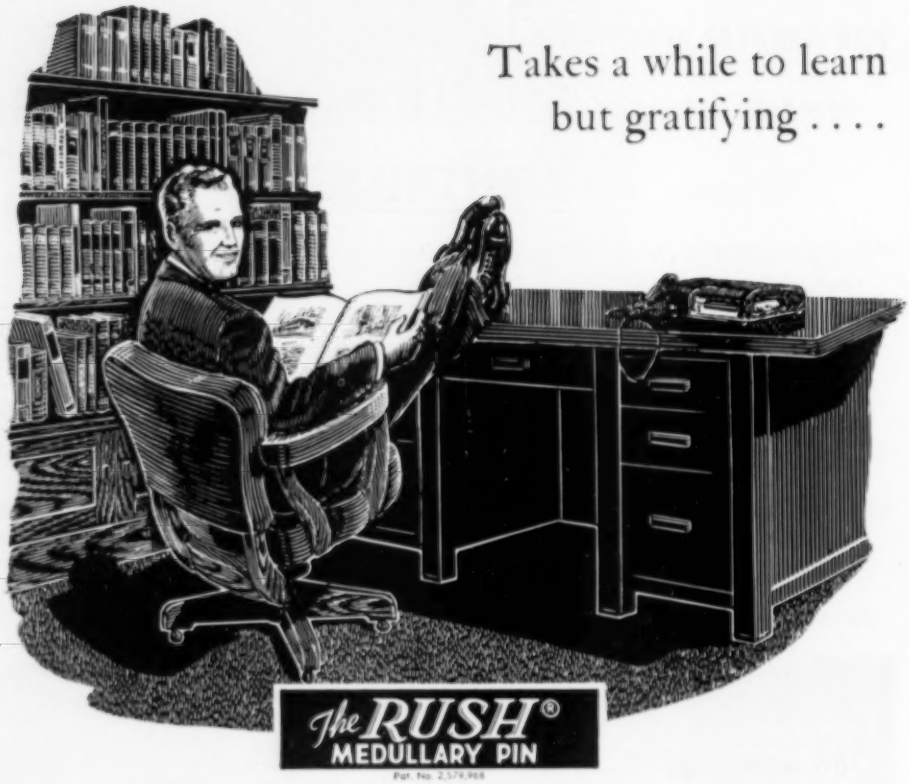
NEUTRILIUM® is the most non-corrosive metal known to science. Its proven super-strength lends an assurance of permanence to internal fixation of the trochanteric area. This neutral, non-magnetic, homogenetic alloy is entirely inert and therefore compatible with human bone or tissue, remaining unaffected by body chemistry.

NEUFELD BONE SCREWS — of ***NEUTRILIUM®*** — are cold forged and, unlike other metals, appear to be unbreakable under maximum human pressures. Heads will not twist off during application or in actual use.

GENUINE NEUFELD NAILS and SCREWS — of ***NEUTRILIUM®*** — made only by MEDICAL RESEARCH SPECIALTIES, Loma Linda, California, are sold nationally by leading surgical and orthopaedic supply dealers.

NEUTRILIUM® *is a registered Trade Name of Medical Research Specialties.*

NEUFELD FEMORAL NAIL PLATE
Used for internal fixation of intertrochanteric and subtrochanteric fractures.
Write for descriptive literature.
MEDICAL RESEARCH SPECIALTIES
Loma Linda, California



Takes a while to learn
but gratifying . . . .

The RUSH®
MEDULLARY PIN
Pat. No. 2,579,968

Proper application of the RUSH PIN is not always easy. It takes a while to learn. It is quite different in principle and technic from other forms of medullary fixation. It is not designed to impact the marrow cavity, but to accurately transfix the fractured bone by points of pressure, precisely applied.

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The patient is more comfortable, the hospital stay is shortened. And best of all, the recovery time and residual disability can be markedly lessened.

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EXCLUSIVE MANUFACTURERS OF **RUSH** MEDULLARY PINS AND INSTRUMENTS
Publishers of **"ATLAS OF RUSH PIN TECHNICS"** by LESLIE V. RUSH, M. D.

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confirm daily in practice
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overwhelmingly favored by physicians in rheumatoid arthritis and bronchial asthma

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METICORTEN, 1, 2.5 and 5 mg. white tablets.

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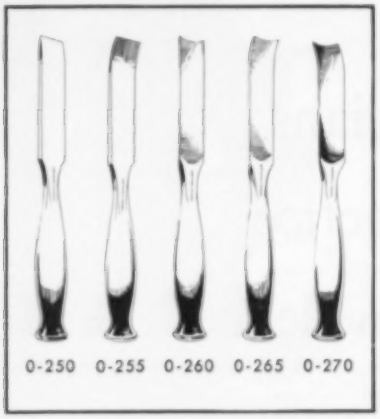
SMITH-PETERSEN OSTEOTOMES and GOUGES



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0-250 SMITH-PETERSEN OSTEOTOME—straight, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

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CASE 0-295—holds seven Smith-Petersen Osteotomes.

CASE 0-296—holds seven Smith-Petersen Gouges.

CASE 0-297—holds a combination of seven Osteotomes and Gouges.

Cutting edges are protected at all times. Complete unit may be autoclaved.

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Specify Width of Gouges and Osteotomes When Ordering

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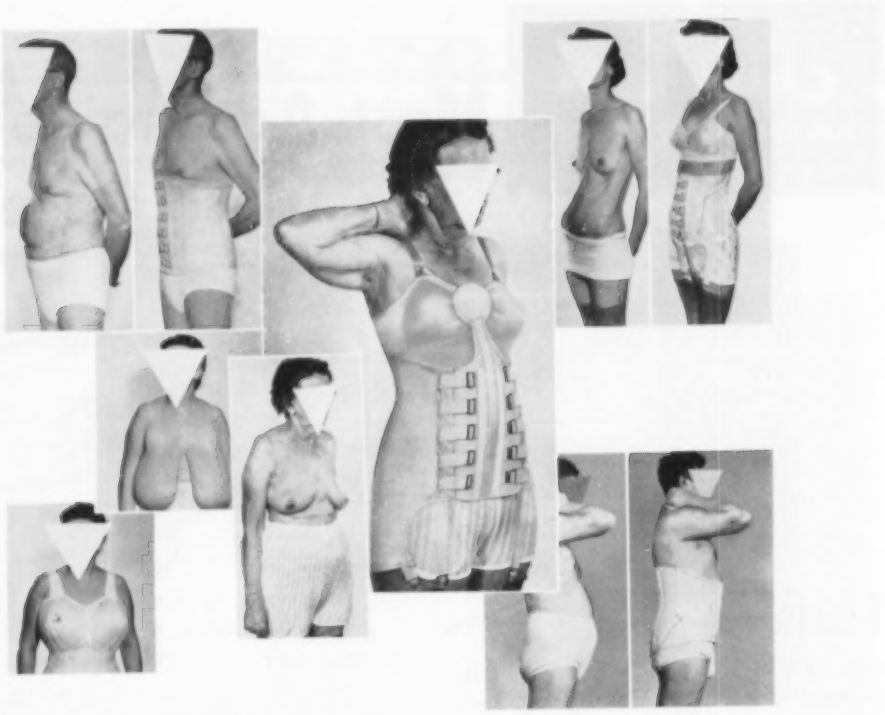

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Child Life
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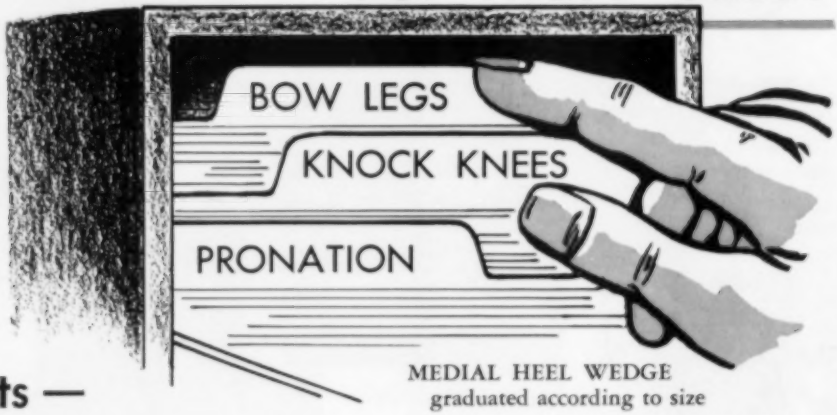
Most Adaptable For These Cases



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CHILD LIFE Arch Feature lasts are made on "Normal Straight Last" lines with allowance on the medial side of the heel to accommodate the basic wedge which is built into the shoe as it is manufactured. The lasts, which have a heel two widths narrower than the ball, are graded in size from AA - EEE; 3½ infant's to misses size 3.

Construction —

Because the shoe is constructed with the basic features listed below, there is need for less additional wedging, and distortion of the shoe is held to an absolute minimum.

GOODYEAR WELT
allows additional wedging

CHROME LEATHER SOLES
finest, best wearing leather

FULL THOMAS HEEL
made of specially compounded rubber

LONG INSIDE LEATHER COUNTER
molded contour for added support

MEDIAL HEEL WEDGE
graduated according to size

RIGHT AND LEFT STEEL SHANK
triple ribbed tempered steel spring

Price —

Because the basic features of the shoe are built-in at the factory, the cost of your adaptation is a small added amount. It means a lower price to the patient and provides many features which could not otherwise be provided — certainly not by a "regular shoe."

Suggested Retail Prices	7.50 —	3½ to 6
	8.50 —	6½ to 8
	9.50 —	8½ to 12
	10.50 —	12½ to 3

Competent Shoe Fitters

The authorized CHILD LIFE dealer in your community has been selected for his knowledge of shoes and his ability to fit juvenile feet correctly. He is particularly qualified to accept your prescription work, and follow your instructions. Write for his name, and for the CHILD LIFE service booklet for the professional man, featuring representative shoes and wedging procedures.

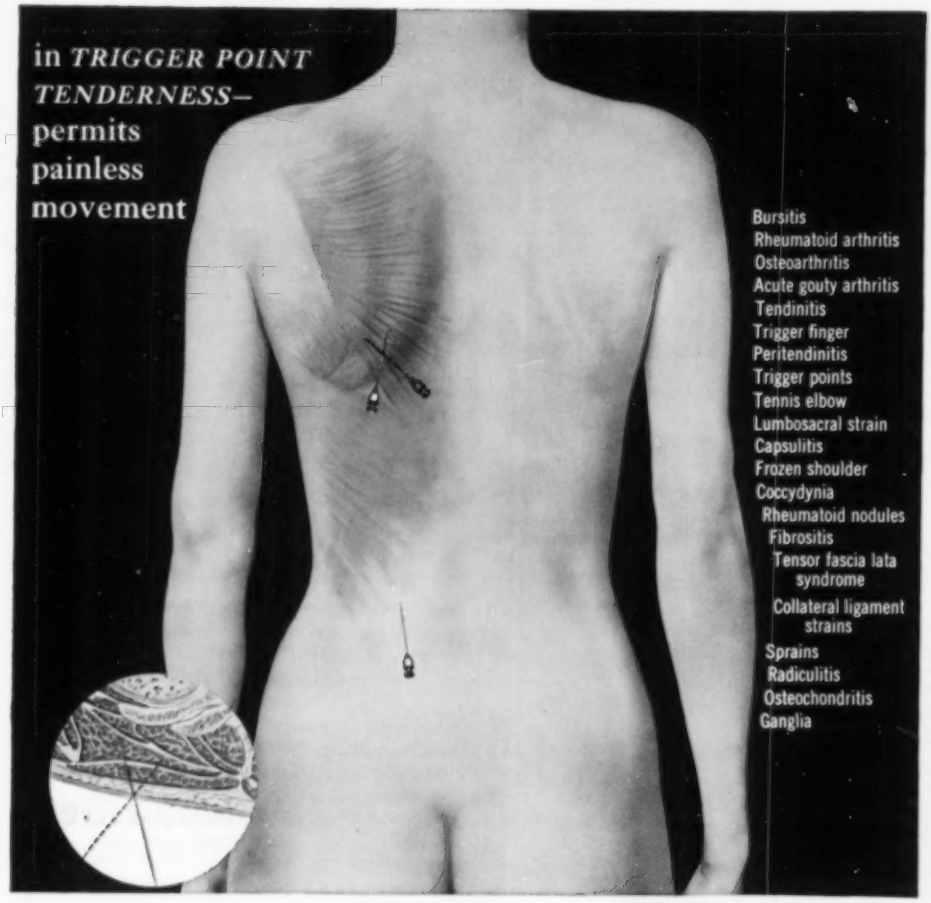
HERBST Shoe Manufacturing Company Milwaukee 45, Wisconsin

NEW

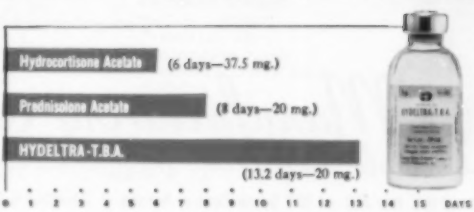
HYDELTRA® -T.B.A.

(Prednisolone *tertiary*-butylacetate, Merck)

for relief that lasts—longer



Duration of relief exceeds that provided by any other steroid ester


Hydrocortisone Acetate
(6 days—37.5 mg.)
Prednisolone Acetate
(8 days—20 mg.)
HYDELTRA-T.B.A.
(13.2 days—20 mg.)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 DAYS

Dosage: the usual intra-articular, intra-bursal or soft tissue dose ranges from 20 to 30 mg. depending on location and extent of pathology.

Supplied: Suspension 'HYDELTRA'-T.B.A.—20 mg./cc. of prednisolone *tertiary*-butylacetate, in 5-cc. vials.

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ACTIVE CORRECTION

with lessened need
for manipulation,
plaster, tenotomy
or anesthetics

with

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Manufacturing Co.

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Knurled locking nuts and rounded edges prevent damage to bed clothes.

An important improvement in the treatment of club feet, positional deformities, tibial torsions, flat feet, congenital hip dislocations and other deformities that respond to correction by kicking.
Lightweight and strong — made of 24 ST aluminum alloy. Precision adjustment — Positive adjustment by degree angles.
Standard sizes — 6″, 8″, 12″, 14″ in stock. 16″, 18″ and 20″ bars available at slight extra cost.

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Pre-fabricated brace parts and orthopedic equipment

NEW ADDRESS!

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CHapman 5-6855

"I WEAR A HANGER LEG • • • •

. . . yet ride a bike and ice skate, and have learned to roller skate, skip, and walk down the steps foot-over-foot". Marion Phillips, school girl, began wearing a Hanger Hip Control Prosthesis at the age of 10. The correct fit and dependable performance of her Hanger Prosthesis have enabled Marion to take part in the normal activities of a teenage girl. Her amazing rehabilitation is not unusual, others have been equally successful, and most Hanger wearers are able to return to a normal life.

• • • • • Hanger PROSTHESES • • • • •

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DALLAS 1, TEXAS
EVANSVILLE, IND.
INDIANAPOLIS 2, IND.
OKLAHOMA CITY 3, OKLA.
PEORIA 4, ILL.
ST. LOUIS 3, MO.
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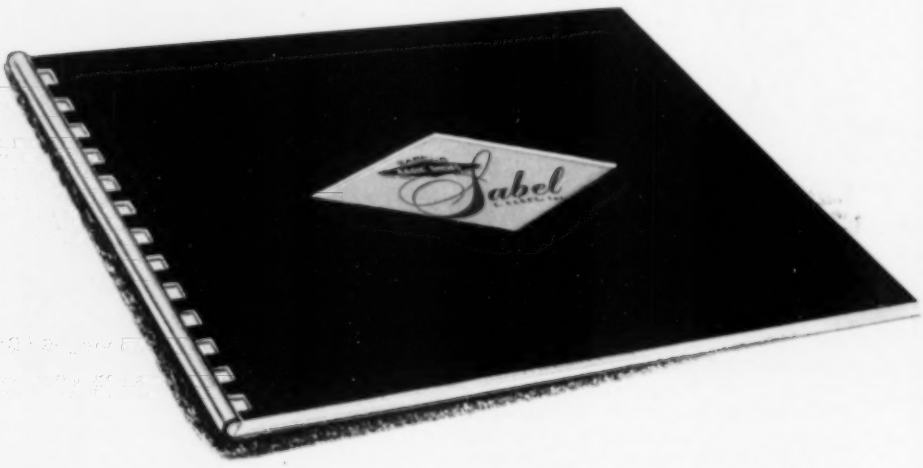

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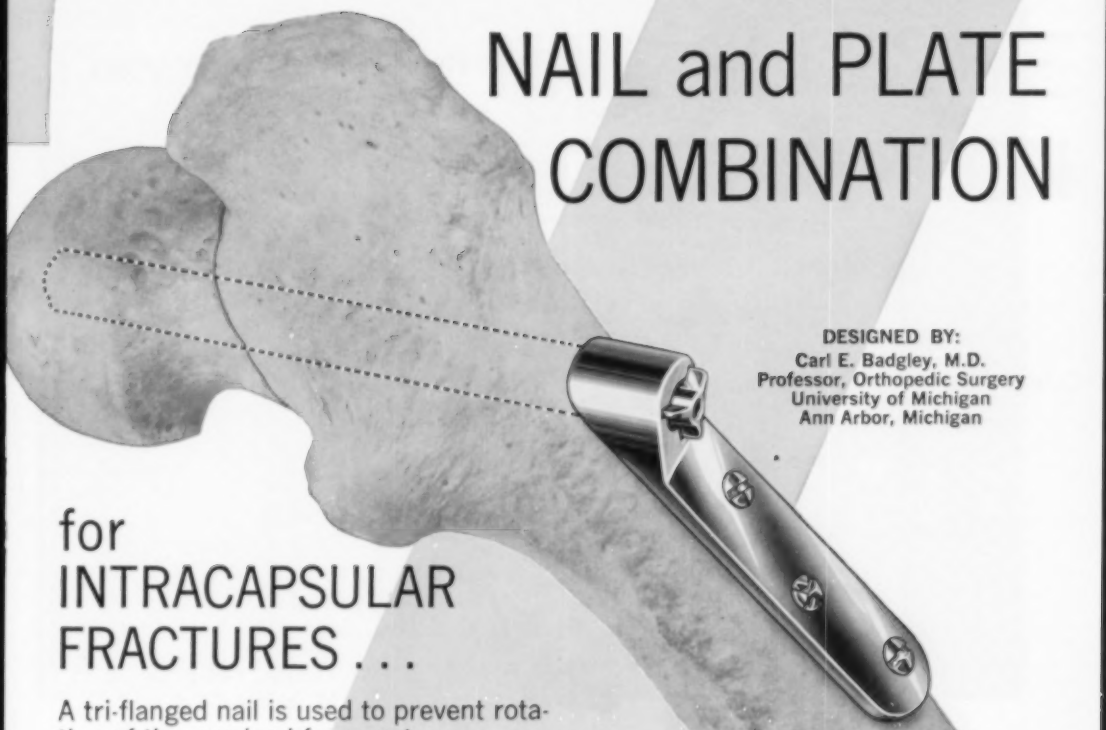

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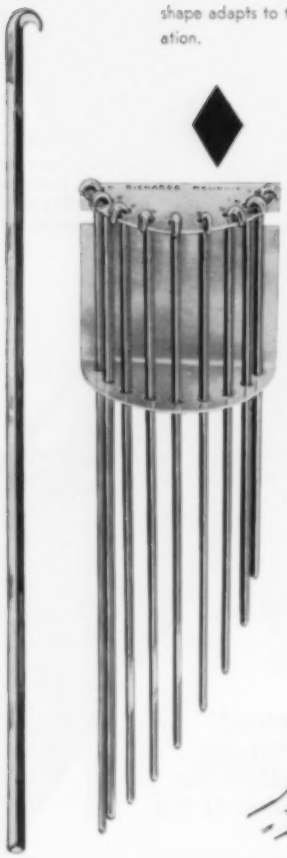

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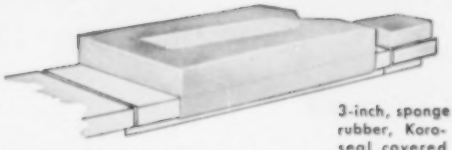

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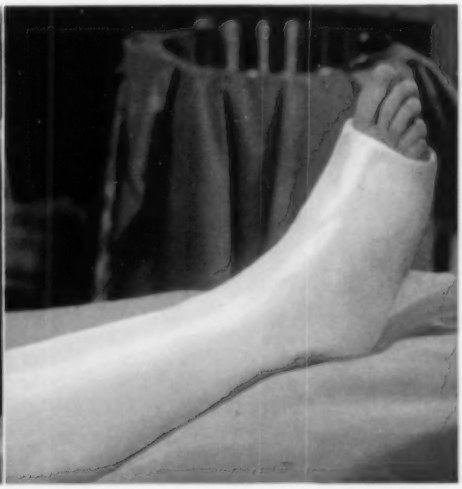

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Elective Surgery on Patients with Respiratory Paralysis

BY VERNON L. NICKEL, M.D., JACQUELIN PERRY, M.D., JOHN E. AFFELDT, M.D., AND CLARENCE W. DAIL, M.D., HONDO, LOS ANGELES COUNTY, CALIFORNIA

From the Respiratory and Rehabilitation Center for Poliomyelitis, Rancho Los Amigos Hospital, Hondo, and the Departments of Orthopaedic Surgery, Internal Medicine, and Physical Medicine, College of Medical Evangelists, Los Angeles

Over a period of many years surgeons have developed a number of procedures which have proved to be of great help in improving function and preventing further complications in poliomyelitic patients. Old techniques have been standardized and new ones have been developed. However, these procedures have not been considered advisable, useful, or as having a place in the management of the severely involved convalescent respiratory patient. This thinking has not been limited to poliomyelitic patients. The same concept has been applied to patients with decreased breathing capacity from other causes, such as traumatic paraplegia, particularly of the cervical level, and to patients with severe chest deformities such as those due to scoliosis.

In the past, these patients were considered poor surgical risks, being too severely involved to justify attempts at functional rehabilitation which, of course, includes surgical procedures. Consequently, until recently poliomyelitic patients with respiratory as well as extremity paralysis have been almost solely the concern of the physicians directing their respiratory management. These physicians have been so successful in the development of mechanical respiratory aids and medical skills that 86 per cent of the patients with respiratory involvement now survive their illness. Moreover, 85 per cent of those surviving become completely independent of respiratory equipment; 41 per cent of the remaining respirator patients use the respirator only for sleeping [1].

Because severe peripheral involvement, particularly of the upper extremities, usually accompanies the respiratory muscle paralysis, the orthopaedic surgeon is challenged to offer an equally complete therapeutic program. To do this successfully, the braces and splints currently being used must be supplemented by reconstructive surgery. With the application of specialized respiratory techniques, these patients need no longer be considered poor surgical risks. This has been demonstrated in most respiratory centers by the demands of surgical emergencies and the ease with which they were tolerated despite respiratory crippling. At Rancho Los Amigos Hospital the concept of doing elective reconstructive surgery was developed by close cooperation between the medical and orthopaedic staffs. A general survey of our first two years' experience in this field has been previously reported [2].

The Respiratory and Rehabilitation Center is aided by an annual grant from the National Foundation for Infantile Paralysis, Inc.

SURGICAL EVALUATION

When it is planned to operate upon a patient with residual respiratory paralysis, we urge that a medical consultant cooperate very closely in the management. The breathing ability of the patient, as well as the type of surgery to be performed, must be considered. Each operation is accompanied by a characteristic amount of postoperative pain, requiring analgesic medication with its associated narcosis and depression of the respiratory center. A further threat to adequate breathing is presented when the operation also results in significant restriction of chest motion because of pain-initiated muscle splinting, a cast, or the mechanics of the surgery.

TABLE I

PATIENT EVALUATION

1. History
   - A. Previous need of respiratory equipment
   - B. Respiratory infections — frequency and severity
   - C. Degree of activity
   - D. Effect of sitting and lying
   - E. Ability to sleep
   - F. Appetite
   - G. Use of braces and corset
2. Physical examination
   - A. Chest cage — shape, size, mobility
   - B. Respiratory muscles
     - (1) Pattern of activity
     - (2) Strength — diaphragm, chest, abdomen, neck
   - C. Cough
3. Laboratory tests
   - A. Chest roentgenogram
   - B. Fluoroscopy of diaphragm
   - C. Alveolar air carbon dioxide concentration
   - D. Vital capacity
     - (1) Positions — sitting, supine
     - (2) Effect of trunk support
     - (3) Elements:
       - a. Tidal volume (quiet breathing)
       - b. Expiratory reserve (maximum expiration)
       - c. Inspiratory reserve (maximum inspiration)

An operation upon the distal portion of an extremity allows fairly free positioning and easy mobilization of the patient. It offers no direct restriction to chest expansion and usually little medication for pain is required; hence few handicaps are placed on the respiratory mechanism. In contrast, surgery involving the trunk, such as spine fusion and abdominal fascial transplants, usually requires considerable medication for pain which limits chest mobility. Chest motion may be further restricted when a body cast is necessary. Any surgical procedure involving the trunk must be considered in this light as one makes the preoperative evaluation. One must estimate the effect of the expected maximum use of narcotics, the type of cast to be used, and the extent to which surgery will involve the thoracic cage.

PATIENT EVALUATION

Adequate pulmonary ventilation is possible when the breathing capacity is greater than the stresses placed upon the body. A patient may evidence no difficulty while he is quiet, but he may be severely distressed by a change of position, increased activity, or the added strain of surgery. This is particularly true of the poliomyelitic patient who may be breathing by substituting less efficient muscles for the paralyzed diaphragm.

The breathing capacity of a patient is a composite of many factors. Strength of the respiratory muscles is basic. Equally important is the state of the lung tissue: is it healthy and flexible? Is the airway intact? The efficiency of these may be altered greatly by the multiple superimposed conditions. The posture or position of the patient can hamper muscle activity or chest expansion, and emotional stress is commonly expressed by hyperventilation. An outline for patient evaluation is presented in Table I.

Knowledge of the previous need for mechanical respiratory aid is most helpful. Frequently patients who have not used a respiratory aid may benefit from or even require the use of such for surgical management. The patient's reserve is partly indicated by the frequency and severity of respiratory infections. Tolerance of activity and changes in position, sleep habits, and a general sense of well-being are further guides. Borderline chronic respiratory inadequacy may be indicated by poor appetite, nausea, irritability, apathy, or even personality changes.

Examination of Breathing Ability

The physical examination should include observation of the shape, size, and rigidity of the chest. The thoracic cage becomes less mobile if its excursions are limited because of the impairment of the respiratory muscles. Paralysis may also produce deformity of the thoracic cage, such as a pear-shaped chest in the growing child. A barrel-shaped chest, with flaring of the distal ribs, results from overactive chest muscles in the presence of a very weak diaphragm. When both the intercostals and the diaphragm are weak, the chest may become flat and tubular.

In the patient with scoliosis severe deformity of the rib cage is particularly likely to develop. This consists of a vertical rigid deformity of the ribs with a considerable shift of the mediastinum. The only non-operative methods available for the correction of scoliosis, except for the use of traction, apply direct pressure on the deformed ribs; thus correction in the curvature of the spine is obtained to a large degree at the expense of further thoracic deformity and decreased function of the lungs.

The next phase in the physical examination is the evaluation of the muscles participating in the breathing pattern. Customarily, we think of respiration as being solely the function of the diaphragm and intercostals, with hardly a thought given to the accessory muscles. Yet the accessory muscles not only reinforce the diaphragm to improve its normal effectiveness but, when it is paralyzed, may provide adequate breathing for routine daily living. These substitute patterns are less efficient and less automatic, that is, they tolerate sleep and stress poorly and may present a false picture of respiratory independence to the casual observer. For this reason a careful diagnosis of the muscle pattern must also be made.

The respiratory muscles may be divided into four groups: diaphragm, abdominals, chest muscles, and neck muscles. Each has its particular function in the normal respiratory pattern. In a normal subject lying supine and breathing quietly, the rhythmical movement is apparent. On inspiration, the chest and abdomen expand simultaneously. This is due to the active contraction of the diaphragm with adequate active chest support. There is no accessory contraction of the neck muscles. Expiration is a controlled relaxation of the inspiratory effort. The abdominal muscles are relaxed during both inspiration and expiration. At the end of expiration there is a momentary rest.

The diaphragm is the principal respiratory muscle, not only because of its anatomical position but also because of its greater endurance, automatism, and efficiency. Its independent function is greatest when the patient is supine. In the erect position the effectiveness of the diaphragm is impaired if the abdominal muscles are paralyzed. Paralysis of the abdominal muscles allows the abdomen to sag with a resulting drop in the diaphragm's position and a decrease in its inspiratory excursion. A corset or binder, or a more rigid

support if it is necessary to support the spine, is a useful substitute for this lost abdominal support.

When the diaphragm is active in the presence of paralyzed chest muscles, the chest retracts on inspiration because of the downward pull of the unopposed diaphragm, resulting in a less efficient and paradoxical respiratory pattern. The abdomen expands as usual.

The strength of the diaphragm may be tested by offering manual resistance to the anterior abdominal wall as the patient pushes against the examiner's hand. A numerical value can be obtained by using graduated weights rather than manual resistance. If the abdominal muscles are strong, care must be taken that these do not substitute for the diaphragm. Litten's sign of intercostal retraction is a convenient indication of a strong diaphragm but can be successfully looked for only in the slender individual. Fluoroscopy is the most direct means of evaluating the activity of the diaphragm since the actual extent of motion can be measured on quiet and forced breathing, as well as on coughing.

Active chest muscles may substitute for a paralyzed diaphragm. They are normally a part of the active respiratory pattern and have the automatism of respiratory-center control. They function effectively with the patient in the supine and erect positions. Normally they are considerably weaker than the diaphragm and are unable to provide independent respiration without considerable development. This method of respiration produces expansion of the chest, with flaring of the lower ribs and retraction of the abdomen on inspiration. During expiration these motions reverse. The resultant rocking motion is another type of paradoxical breathing. Strength of the chest muscles is indicated by the active range of motion of the thoracic cage. When the thorax cannot be expanded without the aid of the neck muscles, there is marked weakness of the chest muscles.

Isolated abdominal muscle activity can supply adequate ventilation only when the patient is erect. The diaphragm is indirectly elevated by the contracting abdominal muscles increasing the intra-abdominal pressure. As the abdominals relax, the diaphragm descends by gravity. Hence expiration is active and inspiration passive. Naturally, as soon as the patient lies down, the force of gravity is lost and an adequate exchange can no longer be accomplished. Both the abdomen and chest flatten on expiration and expand on inspiration.

Trunk flexion (the first phase of a sit-up) is the usual means of measuring the power of the abdominal muscles. However, strong abdominal muscles can accomplish this only if the back is flexible and if the neck muscles are able to raise and support the head. When these conditions cannot be met (as is so common in our patients), palpation of the muscle tone of all four quadrants of the abdomen during the attempted motion will give adequate information. The ability to cough is another indication of abdominal strength.

The neck muscles normally participate only in maximum deep breathing, as with strenuous exercise. They aid by actively elevating the chest cage for greater expansion. Their activity is evident by the prominence of the sternocleidomastoid tendons at the base of the neck. After adequate development these muscles may sufficiently substitute for the other paralyzed respiratory muscles to allow quiet living during the waking hours, but they have insufficient endurance and automatism to be reliable during sleep.

In testing the strength of the neck muscles, one must evaluate the extensors as well as the flexors, even though the flexors are the ones directly involved in respiration. When the patient is erect, the presence of weak extensors will allow the stronger flexors to pull the head forward when an attempt to raise the chest is made. When this happens, the potential respiratory aid of the neck muscles is greatly diminished.

Thus the respiratory muscle pattern is determined by observing the relative retraction or expansion of the chest and abdomen on inspiration and expiration and the relative efficiency of breathing in the supine and erect positions. Two easily recognized signs of respiratory insufficiency are nostril flaring and the activity of the neck muscles. When

these are present, they always indicate a serious respiratory deficit. Table II summarizes respiratory muscle function for review and reference.

An efficient cough is essential for successful respiration and should be evaluated carefully. It is the natural means of clearing the respiratory tree of secretions and foreign objects. Coughing consists in the intake of a relatively large volume of air and then its sudden rapid expulsion. Thus chest or diaphragm power is necessary for the first component and adequate abdominal force for the second. The shoulder muscles may partially substitute during the expiratory phase when the abdominals are paralyzed. The advantage of abdominal support is quickly demonstrated in a patient with paralyzed abdominal muscles by compressing the abdomen manually when the patient attempts to cough.

TABLE II

RESPIRATORY MUSCLE FUNCTION

Muscles Active	Motion		Breathing Capacity		Cough
	Chest	Abdomen	Supine	Sitting	
Diaphragm, chest, and abdomen (normal)	Expands	Expands	Normal	Normal	Strong
Diaphragm and chest (abdomen paralyzed)	Expands	Expands	Normal	Reduced	Weak
Chest and abdomen (diaphragm paralyzed)	Expands	Retracts	Poor	Good	Fair
Diaphragm (chest and abdomen paralyzed)	Retracts	Expands	Good	Reduced	Weak
Chest (diaphragm and abdomen paralyzed)	Expands	Retracts	Poor	Poor	Weak
Neck accessory muscles only (contraction visible)	Elevates	Retracts	Fair	Fair	Weak

Vital Capacity

The most commonly used single test of respiratory function is the measurement of the vital capacity. This is a good general guide if its limitations are recognized and if it is correlated with the history and the findings of the physical examination. It is a measure of the ability to take a single forceful breath, that is, the total reserve strength. However, it gives no indication of the respiratory endurance of the patient, which muscles are active, or his ability to cough. Also, the results vary with the position of the patient and the type of supportive apparatus he may be wearing for trunk stability. The most readily obtainable, accurate instrument with which to study vital capacity is a recording spirometer such as a basal metabolism apparatus with low internal air-flow resistance.

A vital-capacity record (Fig. 1) is made in the following manner: With the patient in the supine position, have the patient breathe quietly for several cycles (this is the tidal volume), then have him expel as much air as possible and follow with a maximum inspiration. The maximum breathing effort should be continued for three to four breaths and then the patient should be allowed to return to quiet breathing. Patterns of breathing should be checked with the patient sitting, and if a constrictive trunk support such as a cast will be used, the test should be repeated with the patient wearing this support. The difference between the end-resting expiratory position and the point of maximum expiration is called the expiratory reserve volume (formerly called supplemental air). It represents the force of the expiratory muscles and clinically is related to the patient's coughing ability. The interval between the end-resting position and the point of maximum inspiration is called the inspiratory capacity (formerly called complemental air) and represents the combined effectiveness of all the muscles active during inspiration.

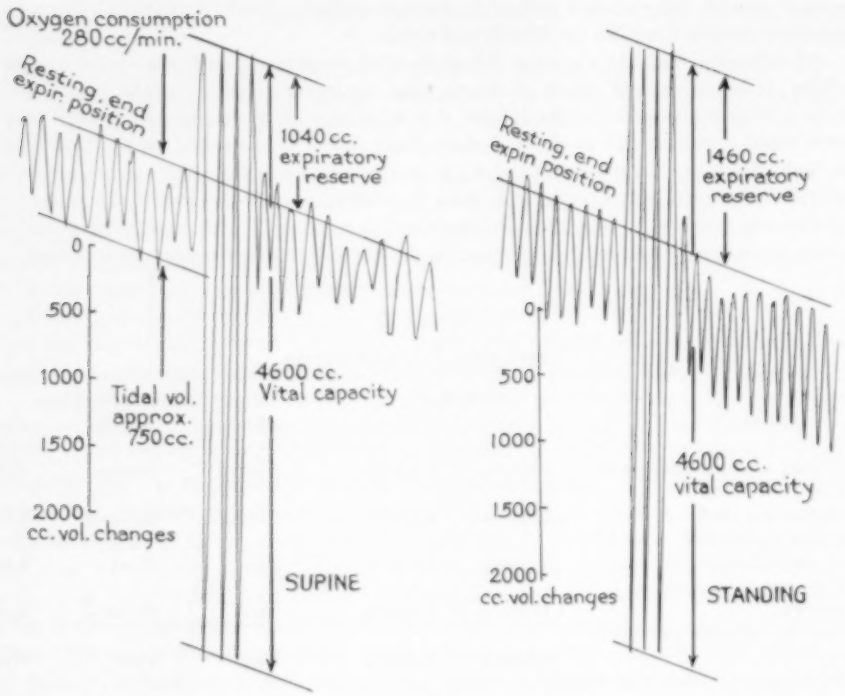

FIG. 1

Normal vital capacity tracings. These tracings were made with a standard basal metabolism apparatus with the patient supine and erect and show lung compartments altered by change in body position.

Since the test cannot indicate the automatism or endurance of the respiratory muscles, it alone cannot indicate the patient's tolerance to sleep or stress or his ability to cope independently with general anaesthesia and postoperative sedation. Total analysis of the patient alone will give this information. The measurement of vital capacity can be used to divide the patients into general functional groups, singling out those who need a particularly careful evaluation. The vital capacity is recorded in milliliters and is then transposed into percentages of predicted normal to facilitate comparisons as the expected volume varies with the age, height, and sex of the patient. Our standards are based on the chart * of expected normals prepared by Collier [2].

All patients with vital capacities of less than 30 per cent of the predicted normal should have mechanical respiratory aid throughout the period of medicinal sedation regardless of the type of surgery being performed. Patients with higher vital capacities who are still partly dependent upon respiratory apparatus are included in this first group.

Patients with vital capacities above 70 per cent of the predicted normal may be expected to tolerate all surgery independently. However, if there is significant abdominal paralysis, an active coughing program is imperative. Because we have noted a decreased morbidity in patients using respiratory equipment, we have adopted the policy of using the tank respirator for almost all patients during the early postoperative period after spine fusion or abdominal fascial transplants.

The large group of patients with vital capacities between 30 and 70 per cent require individual evaluation; their respiratory ability and the nature of the surgery must be correlated. However, some generalization can be made for this middle group. The more

* A copy of this chart is available and may be had upon application to the authors.

dominant the diaphragm and the chest muscles are in the breathing pattern, the less respiratory aid is needed. Thus only the patients with the lower vital capacities who rely on function of accessory neck and abdominal muscles will require respiratory aid for uncomplicated surgery on the distal portion of an extremity. Similarly, the patient with good function of the diaphragm and chest muscles may tolerate spine fusion without aid even though his vital capacity is between 55 and 65 per cent. However, we do not feel that much latitude should be given patients in this group, for they are the ones most prone to a stormy postoperative course, particularly if the cough is not strong.

The many variations between these groups will have to be considered individually. May we caution the reader that whenever doubt exists, he should proceed to use respiratory equipment, as prevention is much easier than the treatment of serious complications. Also, one bad experience may deny the patient any future consideration for surgery.

RESPIRATORY EQUIPMENT

Once the need for mechanical respiratory aid has been determined, the next problem is the choice of the respirator. Patients already using equipment most often continue without change unless the type of surgery dictates otherwise. When they alternate between two or three different machines, the most efficient one is chosen. Usually this is the tank respirator.

In planning for the patient who will need respiratory aid during the postoperative period only, the goal is to select the equipment which offers the most complete respiratory assistance with the minimum amount of adjusting and confusion.

To the uninitiated, the chest respirator (cuirass) may seem a logical answer. Its decreased bulk appears less foreboding and suggests simplicity in operation. This is quite to the contrary. The effectiveness of the cuirass is in proportion to the fit of the shell, and the difficulties in fitting are attested to by the wide variety of sizes and shapes of shells available. Frequently it takes weeks to get satisfactory function and comfort. In addition, this respirator, at best, has only one-half the ventilating potential of the tank. For these reasons we do not consider the cuirass adequate for temporary or emergency use.

The rocking bed is equally undesirable for the postoperative period. The motion of the bed seems to increase the need for pain medication; and swelling in the extremity operated upon appears to be a greater problem, presumably a function of less adequate elevation and the pendulum swing. Furthermore, it is also significantly less efficient than the tank respirator and is totally useless for children as the visceral mass appears to be inadequate for effective ventilation.

The tank respirator is, therefore, preferred for the postoperative patient needing temporary assistance. It offers complete respiratory replacement with a minimum of fuss. Of course, the patient should become acquainted with it prior to surgery. Admissions to the hospital a few days in advance of surgery is most desirable. The machine should be regulated for the patient's usual quiet respiratory rate, and the pressure should be adjusted to give an adequate tidal volume as measured by a spirometer. The proper tidal volume may be estimated with the aid of a nomogram such as the one designed by Radford [4]. Tidal volume is most important since both underventilation and overventilation may cause serious sequelae. The typical hyperventilation syndrome of tingling or numbness in the extremities, dizziness, faintness, hyperirritability of the muscles, and even convulsions is well known. This may be produced as an acute episode by marked mechanical overbreathing for even a short while. Moderate hyperventilation or hypoventilation is difficult to detect except by measurement of the tidal or minute volume of air or the carbon dioxide level in the blood or alveolar gas. Severe hypoventilation is manifest by tachycardia and cyanosis.

As mentioned previously, the tank respirator is also the machine of choice after spine fusion and fascial transplants in patients using other types of respirators. The amount of

trunk flexion necessary to protect abdominal fascial transplants is obtained by the support of a pillow under the hips and thighs. If the patient is large, a giant respirator will be needed. In most spine fusions the cast is not used until the need for postoperative medication and respiratory aid is terminated. Thus no attempt is made to keep the patient in a body cast or plaster bed in the tank respirator. However, a body cast has been used elsewhere successfully by having a large "belly hole" in the cast and by very careful packing about the neck hole to maintain the necessary pressure. When cast fixation should be continued during surgery, anaesthesia and ventilation may best be accomplished under positive pressure. The tracheotomy is done before the permanent cast is applied, and the patient is adjusted to the positive pressure apparatus to the point of comfortable sleep throughout the night prior to any surgery. The source of positive pressure may be the unit with which the tank respirator is equipped or it may be a separate portable machine. Adjustment of the rates of flow and of the amounts of pressure when positive pressure is used is much more of a problem with the tank, as the spirometer is of no use and the tendency toward hyperventilation is very real. The carbon dioxide level in alveolar air has been the most useful guide. The alveolar air, carbon dioxide analyzer gives an immediate reading; this allows for prompt adjustment of pressure. These analyzers are in use in several of the respiratory centers. When one is not available, the determination of arterial carbon dioxide gas tensions could be used if it is made in a reliable laboratory. Under the control of alveolar air analysis, positive pressure ventilation has been used as a routine means of artificial respiration for non-surgical patients for over four years at Rancho Los Amigos Hospital. This same method has been used without incident on numerous patients undergoing major surgery.

TABLE III

CORRELATION BETWEEN VITAL CAPACITY OF A PATIENT HAVING DISTAL-EXTREMITY AND MAJOR TRUNK SURGERY (March 1956 to March 1957)

Vital Capacity (*Per Cent of Normal*)	Number of Operations	
	Tendon Transfers	Spine Fusions
0–10	5	6
11–20	17	10
21–30	9	5
31–40	3	11
41–50	10	5
51–60	4	3
61–70	4	2
71–80	7	3
81–90	4	0
91–100	12	1

Positive pressure may also be given by mask or an applicator held in the mouth. This is a convenient means of supplementing respiration in the non-tracheotomized patient as he travels between the ward and operating room. However, neither of these methods is sufficiently reliable or effective for indefinite use or for use by the heavily sedated patient. The cuirass or chest respirator is another convenient means of protection during transportation to and from the operating room if positive pressure for some reason is not feasible.

Maintaining the Airway

The best respiratory equipment is inadequate if air cannot get through. Aside from

the provision of adequate respiratory power, the maintenance of a continually patent airway must also be kept in mind. For practical purposes the airway may be divided into upper and lower segments. The pooling of secretions in the upper part (nose, mouth, and pharynx), due either to sedation or muscle weakness, is readily handled by thorough suctioning. The lower portion, however, cannot be reached except through a tracheostoma which will allow effective suctioning of a considerable portion of this lower segment. Turning the patient and lowering the head of the bed help in draining the most distal portion of the airway. A good cough is the very best method. Prior to the development of a mechanical coughing machine, patients with inadequate coughs had repeated episodes of atelectasis. Most patients with lowered vital capacities have inadequate coughs. The availability of the coughing machine has decreased the incidence of respiratory complications at our respiratory center. A coughing program is routinely prescribed during the postoperative period (four times daily or more frequently if needed). If there is marked impairment of the patient's natural cough, the *cof-flator* is used. Patients in tank respirators can be coughed by the repeated rapid opening of a porthole at peak inspiration.

In summary, therefore, the management of the patient with respiratory paralysis consists in providing sufficient respiratory force and a patent airway to assure adequate ventilation regardless of the degree of sedation of the patient.

Nursing Care and Training of Personnel

A successful program requires a well trained nursing staff in addition to an informed group of doctors, because the bulk of patient care will depend on the nurses' skill. In a hospital which uses respiratory equipment infrequently, a team of nurses should be trained with all the necessary equipment and alerted to the signs of medical complications. The basic needs are a tank respirator, a suction machine, and a coughing device. The staffs should practice with this equipment until there is familiarity with all phases of its function, and on admission of the occasional respiratory patient they should review everything. Unless the whole staff is familiar with the equipment, standards of surgical risk will be lowered to a dangerous point and unnecessary postoperative complications will arise. The main problem is the subtleness of the early signs of respiratory insufficiency. Cyanosis is a late sign and no one should wait for it, nor should stupor or actual collapse be allowed to occur as only the most heroic treatment will permit a patient to recover from this state.

SURGICAL MANAGEMENT

Once the need for respiratory equipment has been determined and the type selected, the next questions are when to apply the respirator and how long to use it. The basic concept of safe surgical management of patients with respiratory paralysis is the mechanical reinforcement of respiration for the entire interval between the first preoperative sedation and the last pain-relieving hypodermic. This surgical period, as we call it, can be divided into the preoperative, operative, and postoperative intervals. Extended use of respiratory equipment has several advantages. It allows, without risk, the same degree of preoperative sedation that one would choose for the normal patient. One need not compromise the principles of good preliminary preparation of the patient and chance the complications of anxiety with its rapid but shallow breathing pattern, the associated fatigue of tension, or the danger of poor induction into anaesthesia. With equal safety, the patient may be fully relieved of postoperative pain.

Preoperative

If the patient routinely requires the aid of a respirator at any specified intervals, he should also be protected during the period of preoperative sedation, which frequently starts the night before surgery, and he should have the same protection while being transported to and from surgery.

At this hospital elective tracheotomy is done, usually three weeks prior to the surgical procedure. It should be done at the level of the second cartilaginous ring of the trachea so that the tank respirator may be used conveniently, as the collar of the respirator must be below the stoma. A patent tracheostoma makes the lower segment of the airway available for systematic repeated suctioning by the medical and nursing staffs. This method is much more effective than bronchoscopy, which is somewhat traumatic and fatiguing and may only be done by the trained few. Whenever any doubt exists, emergency tracheotomy should be done. It must be remembered in doing tracheotomy that many of these patients will require respiratory assistance similar to that being planned for other surgery.

Operative

General anaesthesia is used almost exclusively at Rancho Los Amigos Hospital. Local anaesthesia without sedation is a tremendous ordeal for any but the most stoical. It readily leads to hysterics, hyperventilation, and a rushed operation. If adequate sedation is used, all the dangers of depressed respiration are present unless respiratory aid is given. Anaesthesia in most of our patients is induced with intravenous pentothal and is carried on with inhalation anaesthesia, usually nitrous oxide and oxygen. If the patient is using a cuirass respirator and will remain supine during surgery on the hand or foot, the use of the respirator may be continued throughout the surgery with anaesthesia being maintained by means of the mask. Otherwise controlled respiration is used with intratracheal intubation and manual compression of the bag. Of course, non-explosive anaesthetic agents are indicated when the respirator or cautery is being used.

Intubation may be done through the mouth, but in the presence of a patent tracheostoma a more convenient orifice of intubation is available. With this technique the tracheotomy tube is replaced by the anaesthetist's lubricated flexible tube of equal size and is taped in place as usual. In the relatively apneic patient the help of one of the surgeons is often welcome to facilitate a rapid exchange of tubes.

Thorough suctioning is done through the tracheostoma, as well as the mouth, prior to dismissal from the operating room.

The patient should usually awake as soon as surgery is terminated. He can then say whether or not he is getting sufficient air from the respiratory equipment. An indication of whether or not the patient is getting sufficient air is the degree of visible chest expansion. A less obvious aid to effective ventilation is the maintenance of an adequate total blood volume for the essential gaseous exchange taking place in the tissues. To ensure this, blood transfusions are given during surgery in amounts equal to the estimated blood loss. The hemoglobin level is determined on the day following surgery and the patient is treated accordingly. Consideration of loss of muscle mass must be made in giving transfusions as the total blood volume is lower in the severely paralyzed patient and moderate bleeding may mean high relative loss. Similarly, excessive blood transfusion must be avoided.

Postoperative

On being returned to the ward the patient is placed in respiratory equipment, and its use is continued as long as narcotics are required for the relief of pain. The respirator must be used if a postoperative complication occurs. For patients requiring equipment just for the surgery, its use is decreased as the need for narcotics diminishes. This is seldom before the second postoperative day. If the patient is alert, in good health, and using essentially no pain medication, use of the respirator may be discontinued for an hour twice the first day, doubling the time daily, with trying to sleep out of the respirator as the final stage. This schedule varies with the tolerance of the individual and no harm results from having the patient in equipment longer than is necessary. The patient's

sense of comfort, general clinical appearance, and vital signs are the main guides to the length of time a respirator need be used. Evidence of fatigue, elevated temperature, respiratory rate or pulse rate indicate the need for increased respiratory protection.

If patients are not using their usual respiratory equipment for the postoperative period, they are gradually converted to their preoperative regimen.

Each patient not wearing a body cast has a preoperative and an early postoperative chest roentgenogram for evidence of unsuspected atelectasis. Atelectasis is characterized

TABLE IV

CLASSIFICATION OF OPERATIONS

	March 1954 to March 1955	March 1955 to March 1956	March 1956 to March 1957
Tendon transfers	32	62	75
Osteotomies	4	22	26
Arthrodeses	16	28	44
Spine fusions	3	25	34
Cervical-spine fusions	0	4	12
Fascial transplants	3	15	12
Miscellaneous	5	10	63
Total	63	166	266

TABLE V

RESPIRATORY EQUIPMENT

	March 1954 to March 1955	March 1955 to March 1956	March 1956 to March 1957	
Tracheotomy	0	26	81	
Preoperative equipment	0	27	67	
Tracheotomy done preoperatively	0	4	17	
To surgery with equipment	0	13	107	
From surgery with equipment	0	36	112	
Postoperative respiratory aid	0	48	128	
Postoperative cof-flator	0	10	266	(routine postoperative order now)
Tank respirator at onset of disease	20	114	153	

by rapid pulse rate, fever, and restlessness. It may be fatal. Unfortunately all of these signs may be absent, the early chest roentgenogram may be normal in appearance, and a massive atelectasis may develop with the only sign being the generally poor appearance of the patient. One of the valuable signs in the early diagnosis of atelectasis is a decrease in the vital capacity.

Antibiotics are included in the standard postoperative orders for patients using respiratory equipment. In patients not using a respirator, they are used only with specific indications.

DISCUSSION AND RESULTS

The initial objective of the surgical staff in prescribing mechanical respiratory aid for patients with varying degrees of respiratory paralysis was to enable them to survive

the ordeal of an operation under adequate anaesthesia. It quickly became evident that this goal of survival could be raised to that of maintaining good health throughout the surgical period despite general anaesthesia and adequate postoperative analgesia. To the amazement of the staff, the severely crippled respiratory patient, receiving adequate mechanical ventilation, routinely presented a much more benign postoperative course than the more normal patient.

In advocating this program we realize that certain patients will receive more respiratory assistance than is essential for survival. We also recognize that many patients have undergone surgery without respiratory aid despite low vital capacities. No attempt has

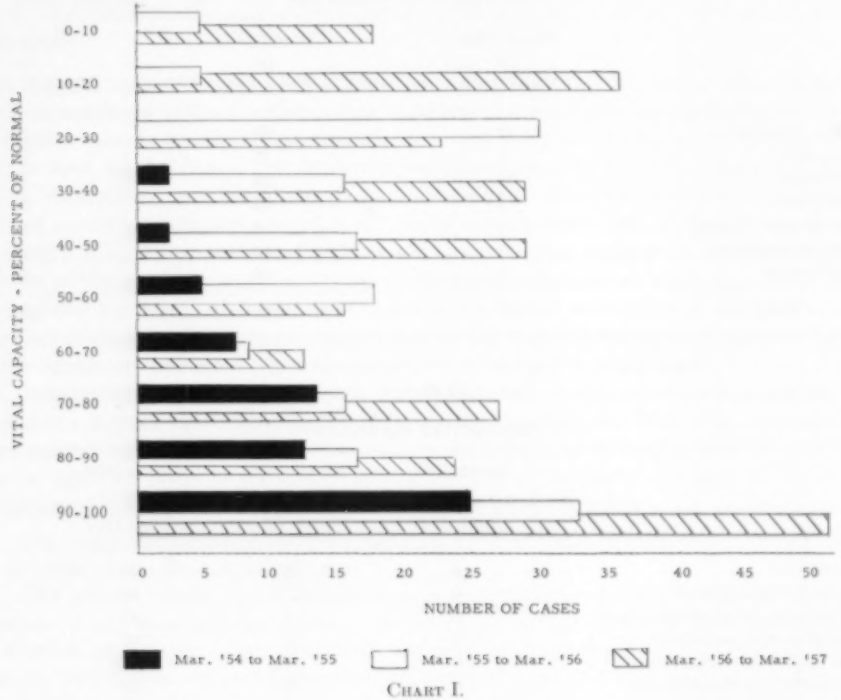

CHART I.

been made to determine the absolute minimum of need, as the current methods of evaluation are not sufficiently accurate to specify the peculiarities of one particular person. It is our contention that the same philosophy which is so generally accepted of replacing lost blood during surgery rather than awaiting the development of shock should be applied to the use of mechanical respiratory assistance. These same principles apply to the many other types of illnesses which are associated with respiratory impairment, such as tetraplegia and chest deformity due to spinal collapse or scoliosis.

An additional year's experience to that previously reported [3] has reinforced the impression that generous use of respiratory equipment is good medical judgment. The severity of the respiratory paralysis is not a factor in determining the advisability of a surgical procedure. It merely indicates the degree to which respiratory aid will be needed.

As a means of illustrating the fact that the vital capacity does not dictate the amount of surgery a particular patient can tolerate, all the tendon transfers and spine fusions done this past year were classified by the vital capacities of the patients undergoing these procedures (Table III). These two operative procedures were selected as examples of minor and major stresses.

During the twelve-month period between March 1956 and March 1957, 266 ortho-

paedic operations were performed; 26 per cent of this number were on patients routinely using respiratory equipment daily. In all, 48 per cent of the patients operated upon received respiratory aid postoperatively. There were no respiratory complications during the year in the group of 266 patients. The only complication was a minor episode of fluid intoxication in a small child.

An analysis of the three years' experience is presented (Tables IV and V). The number and type of operations performed is similar to that of most orthopaedic reconstructive services (Table IV). A comparison of the frequency with which respiratory equipment has been prescribed for the surgical period each year shows a progressive increase in its use (Table V). This is correlated with the increased number of operations in patients with respiratory paralysis (Chart I).

SUMMARY

1. Respiratory paralysis due to poliomyelitis is commonly accompanied by severe involvement of the trunk and extremities.

2. These patients are in great need of complete orthopaedic care — including reconstructive surgery.

3. The breathing ability does not dictate a patient's ability to tolerate surgery. It merely indicates his relative need for mechanical respiratory assistance during the surgical period.

4. The use of respiratory equipment in the early postoperative period will decrease the systemic reaction to surgery and its associated medications by supporting the patient's respiratory system and thus reducing the postoperative morbidity.

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Congenital Anomalies of the Hand

Part I

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Malformations of the hand in newborn infants are comparatively uncommon. The forms which these malformations assume are extremely varied, however, some being so bizarre as to almost defy description (Figs. 1-A through 1-Q). Previous attempts at classification have only resulted in a conglomeration of names which neither describe definite patterns nor conjure clear pictures. This confusion has been increased by the current use of a nomenclature derived from Latin and Greek roots. Usage and clarity have made such terms as *syndactylism* and *synostosis* acceptable, but we fail to see that any advantage is gained by using such abstruse words as *ectrodactylism* and *poikilodigits* instead of their English equiavlents *aborted fingers* and *multiform digits*. Although the meaning of *brachydactylism* and *megalodactylism* is clear, it would seem preferable to use the simpler terms *stunted fingers* and *overgrown fingers*.

Bilateral malformations of the hand have been found in some newborn infants (Figs. 2-A through 2-G). Occasionally, in these infants, the deformity in one hand mirrors that in the other.

Generalized congenital affections, such as arthrogryposis with local manifestations and central-nervous-system lesions which cause secondary crippling of the hand, are not included in this paper. Anomalies of the wrist and forearm which materially hamper the functioning of the hand are mentioned, however. Some of these deformities co-exist with those of the hand.

It should perhaps be pointed out that not only the external appearance but also the skeleton of the hand may be abnormal: bones may be missing or there may be extra ossicles; stunting or overgrowth may be present; and the bones may be confluent or malaligned (Figs. 3-A through 3-L). Another possible deformity is congenital dislocation of a digital joint, and there may be a deficiency in the muscular and tendinous structures. The vascular system may be aberrant and a pathologically significant possibility is the presence, under the volar carpal ligament and palmar aponeurosis, of a hidden cavernous hemangioma which later, when the child is two or three years old, will appear as a painful swelling (Figs. 4-A through 4-D).

Considerable effort has been made to determine the causes of the different congenital deformities of the hand. For a few it has been found that heredity is a definite factor. Other possible causes which have been suggested by various authors, but about which it is impossible to be certain, are embryonic amputation, position of the foetus in the uterus, and scarcity of amnionic fluid (constriction bands have been attributed to this cause). There is some evidence that virus infections, including certain forms of measles, in the mother during the early months of pregnancy may cause congenital abnormalities; and the results of animal experiments have indicated that irradiation, defective diet, vitamin deficiency, low temperature, or inadequate oxygen may also be factors.

It is possible to conjecture that disease or injury to the embryo might cause deformities in which all the fingers or even the entire hand is missing. This theory will not explain many deformities, however, including those in which the anomaly of one hand mirrors that of the other or those in which there are more, not less, than the normal number of fingers.

FIG. 1-A FIG. 1-B FIG. 1-C FIG. 1-D

Figs. 1-A through 1-Q: Congenital malformations of the hand, including absence of digits, stunting, overgrowth, confluence, bifurcation, palmar cleft, and clubbing at the wrist.

Figs. 1-A through 1-D: Absence of digits. These deformities are unilateral.

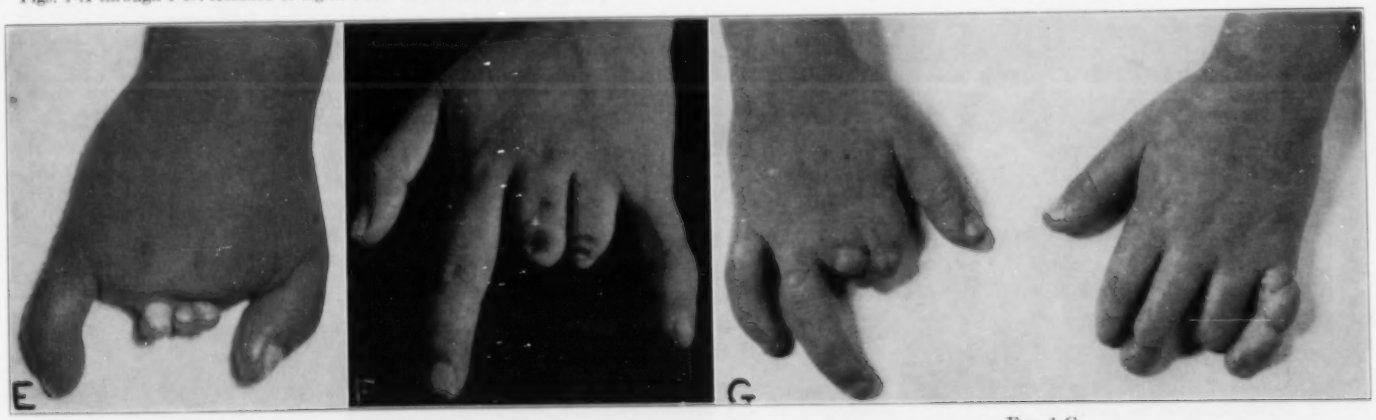

FIG. 1-E FIG. 1-F FIG. 1-G

Figs. 1-E and 1-F: Absence of digits; unilateral deformities.

Fig. 1-G: Bilateral deformities. In one hand the ring and long fingers are aborted, while in the other the ring finger is stunted, and there are constriction bands on the long and little fingers.

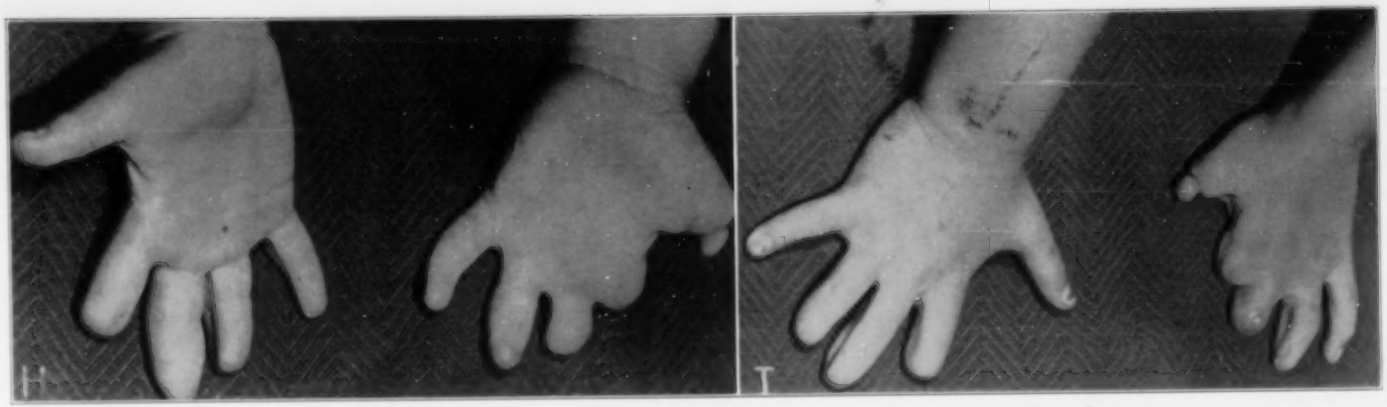

FIG. 1-H FIG. 1-I

Fig. 1-H: Volar view of bilaterally deformed hands. The deformities include aborted fingers; stunted, nailless fingers; and an aborted thumb with a constriction band at the tip.
Fig. 1-I: Dorsal view of the hands shown in Fig. 1-H.

FIG. 1-J FIG. 1-K FIG. 1-L FIG. 1-M FIG. 1-N

Figs. 1-J and 1-K: Dorsal and palmar views of a hand in which the only digits are two webbed thumbs.
Fig. 1-L: Hand with a thumb hanging by a soft-tissue stalk.
Fig. 1-M: Hand with a supernumerary thumb.
Fig. 1-N: Thumb with a bifid distal phalanx.

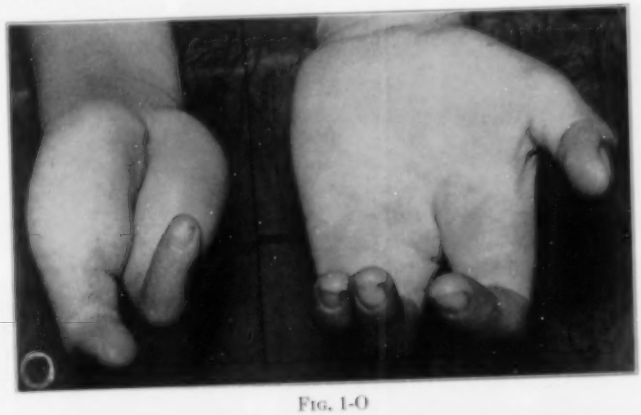

FIG. 1-O

FIG. 1-P FIG. 1-Q

Fig. 1-O: Volar view of bilaterally cleft hands, each with one gigantic finger.
Fig. 1-P: Dorsal view of the hands shown in Fig. 1-O.
Fig. 1-Q: Hand with confluent fingers and clubbing at the wrist.

In some newborn infants, the arm is missing and the hand is directly connected to the torso as in a seal (phocomelus); in others the digits are webbed, as in birds, or are closely bound, as are those of syndactylous apes. Deformities such as these have given rise to various evolutionary theories, of which the concept of phylogenetic polydactylism is an example. According to this doctrine the normal five-fingered hand of man is a derivative of an ancestral limb possessing six or more digits. The implication of this concept is that an anomalous hand in which there are less than five rays represents a future phase of the evolutionary trend, while conversely, a hand with supernumerary fingers represents an atavism. Concerning this theory Frederic Wood Jones has aptly written: "It is upon the occurrence of cases of additional digits in man and in the lower forms that a great deal of reliance has been placed by upholders of theories of phylogenetic polydactylism. But some caution is needed. Generally one may say it is easy to overdo the building of theories of normal phylogeny and ontogeny based upon studies of what are pure anomalies, malformations, or freaks. Babies are sometimes born with two heads, but this fact affords no safe ground for believing that our single head has been derived from a former condition of polycephaly."

Etiological theories, intriguing as some of them are, can hardly contribute significantly to the amelioration of a condition which is present at birth. Thus, a crippled hand in a newborn infant must be regarded as an irreversible calamity and every effort must be made to enhance the utility of the affected limb, regardless of the name or cause of the deformity. A discussion of the possible causative factors would be of value only if it led to the prevention of the deformity.

CRITERIA FOR SURGICAL INTERFERENCE

Without treatment many deformed hands do well functionally, and surgical interference is only justified if it enhances function. Cosmetic appearance is important, but not as important as utility: a malformed hand that is useful is to be preferred to one that appears less unsightly but is not useful. Even the anatomical configuration of the hand, important as this may be, is a secondary consideration.

Contra-Indications to Surgery

The hand is a brain-controlled organ, one of the functions of which is to enhance perception. It gathers information on the size and shape of objects, their position in space, their properties as to hotness or coldness, and the type of sensations they produce, whether pleasant or painful. After imparting this information to the brain, it may then serve to give expression to the resulting pattern of motor activity conceived and coordinated in the cerebral cortex. It is obvious that surgery should not be done on the hand of a child who is mentally deficient; fortunately, however, most children with congenital malformations of the hand are normal in this respect.

The arm and forearm, which link the hand to the body, contribute to the functioning of the hand in two ways: they serve as a segmented bridge across which sensory impressions are conveyed to the brain and they act as accessories in the discharge of the motor responses stimulated by the cortex. In its motor activities the hand is dependent not only upon the integrative action of the brain but also upon the presence of stability of the wrist proximally, free pronation and supination of the forearm, and good functional movement of the elbow and shoulder. One would hesitate to operate upon the hand in the absence of any of these factors. A further consideration in the decision to do surgery is the condition of the sensory nerve system and the status of the musculature, for surgery should be avoided if the sensibility of the hand is dulled or if muscular control is insufficient.

Timing of Surgery

A question that often arises is at what age surgery should be performed upon children with congenital malformations of the hand.

Functional use is the greatest stimulus to growth and to the development of muscle coordination: fingers will grow and become more useful if they are freed from restraint and placed in good functional position. For this reason, reconstructive surgery should be initiated as early as is feasible, preferably during the first year of life.

In most cases of congenital malformation of the hand, there is no reason to postpone surgery until the child has reached maturity. Of course, the child should not be subjected to such operations as arthrodesis, arthroplasty, or joint resection, procedures which may damage the epiphyseal plate and stunt the growth of the involved bones. Other operations, however, including separation of connected fingers, osteotomy of the shaft of the bone,

Fig. 2: Deformities of the skeleton of the hand, including absence of rays, stunting, bifurcation, confluence, and clubbing. *A* through *E:* Absence of digits. The hand shown in *C* is the same as that shown in Fig. 1-F. *F:* Hand with only three digits. The carpal bones merge at the base of the two ulnar metacarpals. In this patient there was also radio-ulnar diastasis near the elbow. *G:* The first metacarpal intercepts the metacarpal of the index finger. *H:* Roentgenogram of the hand shown in Fig. 1-M. *I:* Incomplete fourth metacarpal. *J:* Confluence of two phalanges. *K:* This deformity is similar to that shown in Fig. 1-L. *L:* Lateral roentgenogram of the hand shown in Fig. 1-Q.

FIG. 2

tendon lengthening, and digital shift, can safely be carried out early in life, even during infancy.

The psychological orientation of the child also must be taken into consideration. It has been our impression that younger children adjust most easily to a disfigurement that sets them off from others and accept their deformity with greater grace and docility. We try to complete reconstructive surgery during the pre-school years so that by the time the child enters school, he will have become used to his deformity in the form in which it will remain for the rest of his life. Another reason for performing surgery early is that it takes time and time is not important to the pre-school child. A final consideration is that most reconstructive surgery involves the transference of pedicled skin grafts from the abdomen to the hand, a procedure which entails considerable inconvenience, and this too is better tolerated by younger children.

Specific Purposes of Surgery

In exploring and examining the objects presented by the external world and in accepting or rejecting these objects, a normal hand performs many refined functions such as touching, feeling, grasping, and pinching. To say that such a hand serves as a paddle, club, hook, pincers, or conveyor is to oversimplify movements which are comparatively complicated. Malformed hands present a different situation, however, and in discussing these hands refinements should be avoided and the simpler, more basic functions considered. A malformed hand which consists of no more than a nubbin can serve only as a paddle or club. If such a hand can be converted into a hook, something has been accomplished, and if this hook can be made to grasp or pinch in even an elemental way, then much has been done to improve its function despite the lack of more intricate movements.

The *pulp-to-pulp pinch* which is produced by the extrinsic muscles alone is weak. If the intrinsic muscles, especially those of the thenar group, are also involved, a stronger pinch is obtained. The movement in which the palm serves as an apposition platform and the fingers close on it, or on an object supported by it, is called *grasp;* this action requires some force but not a great deal. A similar movement, but one in which the extrinsic muscles are only partly aided by the intrinsic muscles, is referred to as *pulp-to-palm apposition*. *Grip*, another action of the hand, denotes greater force. In this movement, all the power of both extrinsics and intrinsics is exerted against the palm, either directly or through an intervening solid object; the broader the palm, the stronger the grip.

A distinction should be made between *side-to-side* and *pulp-to-pulp* pinch. The former is a possible function of all the fingers and is brought about by the apposition of the adjacent surfaces of two neighboring digits. This form of pinch is at best weak. In *pulp-to-pulp* pinch, the pad of the distal phalanx of the thumb is placed in apposition to the corresponding pads of the other fingers. This form of pinch is more efficient. Another possible type of pinch is to press the distal volar pad of the thumb against the volar pads of the first and second phalanges of the other fingers or even against the distal portion of the palm; neither of these movements is true *pulp-to-pulp* pinch, however.

The primary purpose of the surgical reconstruction of congenitally malformed hands is to obtain grasp and appositional or pulp-to-pulp pinch. Improvement of the cosmetic appearance is incidental and is never undertaken at the expense of function.

SURGICAL PROCEDURES

Restorative surgery often necessitates preliminary or simultaneous skin-grafting. Defects created at surgery can be covered by one of three means: local flaps, free skin grafts, or pedicled skin grafts. Local flaps are used to line the areas which are directly

Fig. 3: Bilateral congenital dislocation of the index finger in a father and son. The son was one year and two months old. *A* and *B:* Dorsal and volar views of the father's hands. *C* and *D:* Dorsal and volar views of the son's hands. *E:* Roentgenogram of the father's hands showing the index and adjacent fingers. *F:* Roentgenogram of the son's hands. *G:* Operative exposure of one of the son's index fingers. The base of the proximal phalanx was found lying on the radial side of the head of the supporting metacarpal.

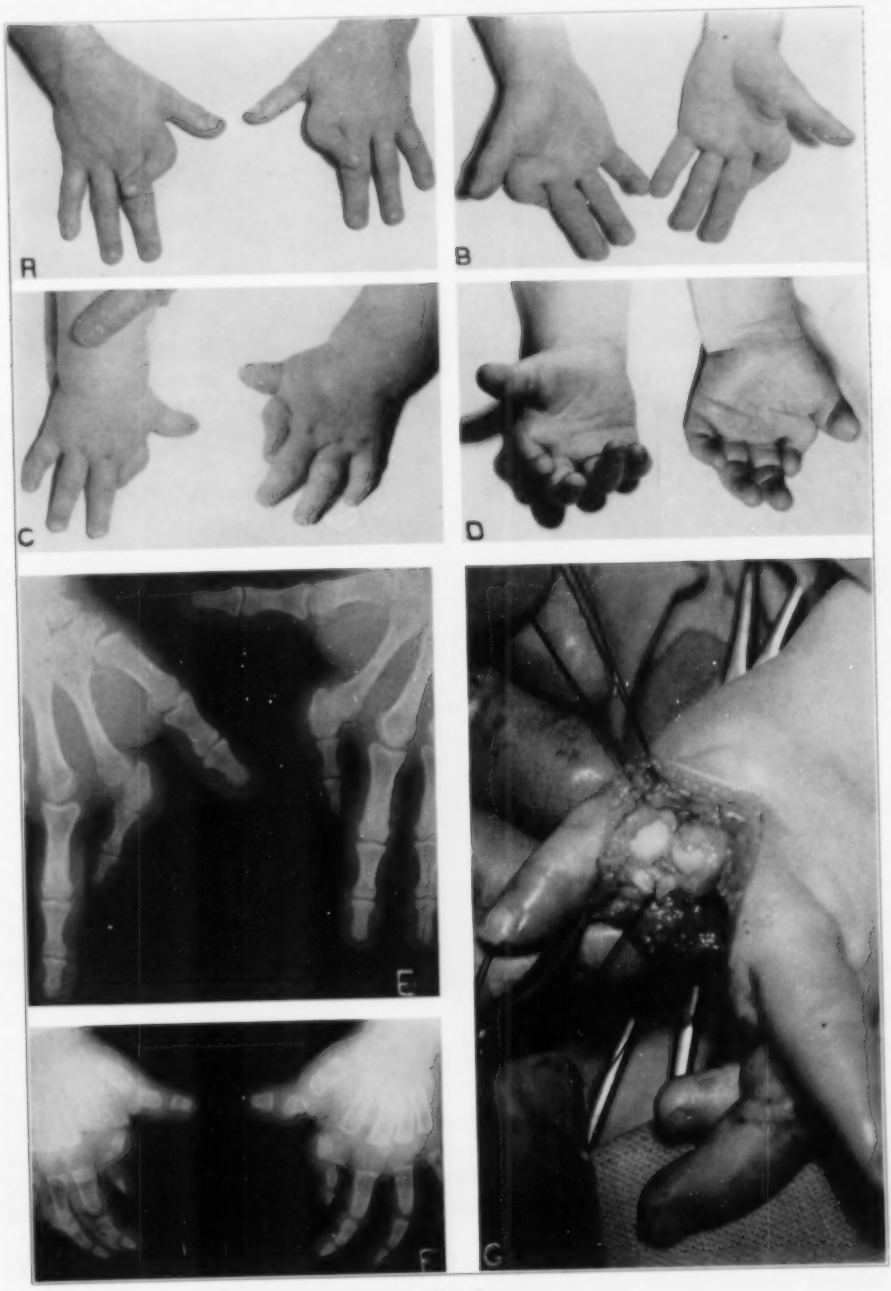

FIG. 3

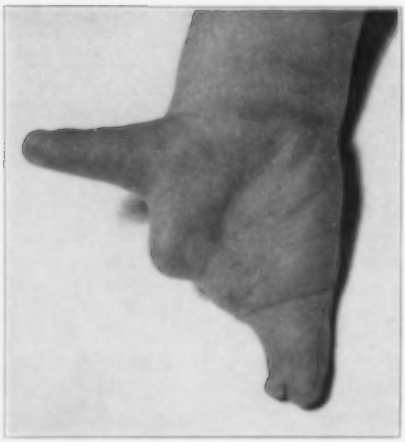

FIG. 4-A

FIG. 4-B

Figs. 4-A and 4-B: Volar and dorsal views of the right hand of a boy four and one-half years old. The flexor hallucis longus tendon was missing, and the thumb was held in apposition by the unopposed extensor hallucis longus.

FIG. 4-C

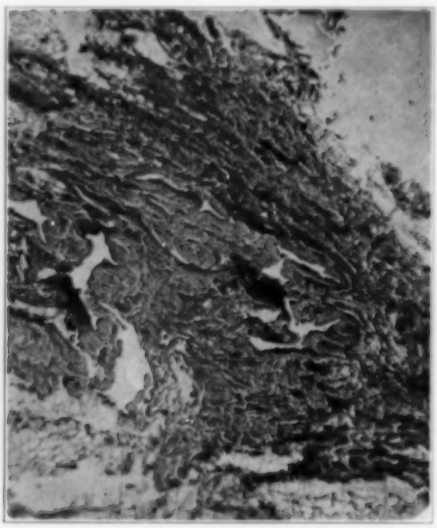

FIG. 4-D

Fig. 4-C: Surgical exposure of a cavernous hemangioma in the hand of a three-year-old boy.
Fig. 4-D: Photomicrograph showing a section of the hemangioma shown in Fig. 4-C.

involved in motion and perception; if these flaps are sutured under tension or are twisted unduly, they may slough and leave a contracted scar. Free full-thickness skin grafts are invaluable for covering the sides and the volar pads of the distal phalanges; they should not be applied over exposed nerves, muscles, and tendons as they tend to bind and scar.

In young children the covering provided for the hand should be sufficiently lax so that it will not restrain growth and expansion; it must be pliable, yielding, and capable of stretching. For this reason we favor pedicle grafts. In applying these grafts, we place more skin on the hand than is necessary, allowing for wastage and future refinements. One ad-

FIG. 5-A

FIG. 5-B

FIG. 5-C

Figs. 5-A through 5-F: The right hand of a girl born with a supernumerary thumb.
Figs. 5-A and 5-B: Photographs, made when the patient was five months old, showing the right hand clenched and open.
Fig. 5-C: Roentgenogram of the same hand. The thumb on the outside with the smaller bones was ablated.

FIG. 5-D

FIG. 5-E

FIG. 5-F

Fig. 5-D: Dorsal view of the hand after surgery. Note the range of abduction in the remaining thumb.
Fig. 5-E: Volar view of the right hand (on the left) next to the normal hand.
Fig. 5-F: Volar view of the right hand. Note the range of flexion in the thumb.

vantage of pedicled grafts is that they have an areolar seam which allows the underlying joint to move and the tendons to glide. One great disadvantage, however, is that they are devoid of sensory nerves. For this reason they should not be used to cover the volar surface of the hand and fingers.

In the remaining portion of Part I, the treatment of supernumerary digits and palmar clefts will be discussed and the surgical methods used to obtain such simple, elementary functions as side-to-side and pulp-to-pulp pinch will be described. In the procedures involved, pedicled skin grafts are not used. Procedures in which pedicled skin grafts are of paramount importance will be discussed in Part II.

The treatment of syndactylism has features in common with both the two major types of treatment discussed in Parts I and II. In some cases, local flaps and free skin grafts are used in the separation of the confluent fingers, while in others pedicled skin grafts are used. Discussion of this condition is given at the end of Part I.

Ablation of Supernumerary Digits

An extra finger or thumb is removed for cosmetic reasons. This operation requires no ingenuity and creates no problems (Figs. 5-A through 5-F). The only special factor to keep in mind is that there may be a cartilaginous epiphysis at the base of the proximal

FIG. 6-A

FIG. 6-B

FIG. 6-C

Figs. 6-A through 6-K: Hands of a boy born with bilateral palmar cleft.
Fig. 6-A: Volar view of the left hand made when the boy was four months old.
Fig. 6-B: Roentgenogram of the same hand.
Fig. 6-C: Dorsal view.

FIG. 6-D

FIG. 6-E

FIG. 6-F

Fig. 6-D: Volar view of the right hand.
Fig. 6-E: Roentgenogram.
Fig. 6-F: Dorsal view.

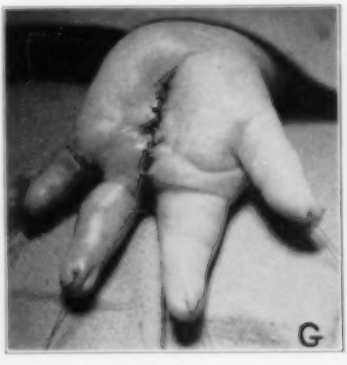

FIG. 6-G

FIG. 6-H

FIG. 6-I

Fig. 6-G: Volar view of the left hand after closure of the cleft and deepening of the web space between the two ulnar fingers.
Fig. 6-H: Volar view of the right hand following closure of the cleft.
Fig. 6-I: Dorsal view of the right hand. Note the rectangular flap of skin which was used to span the web space.

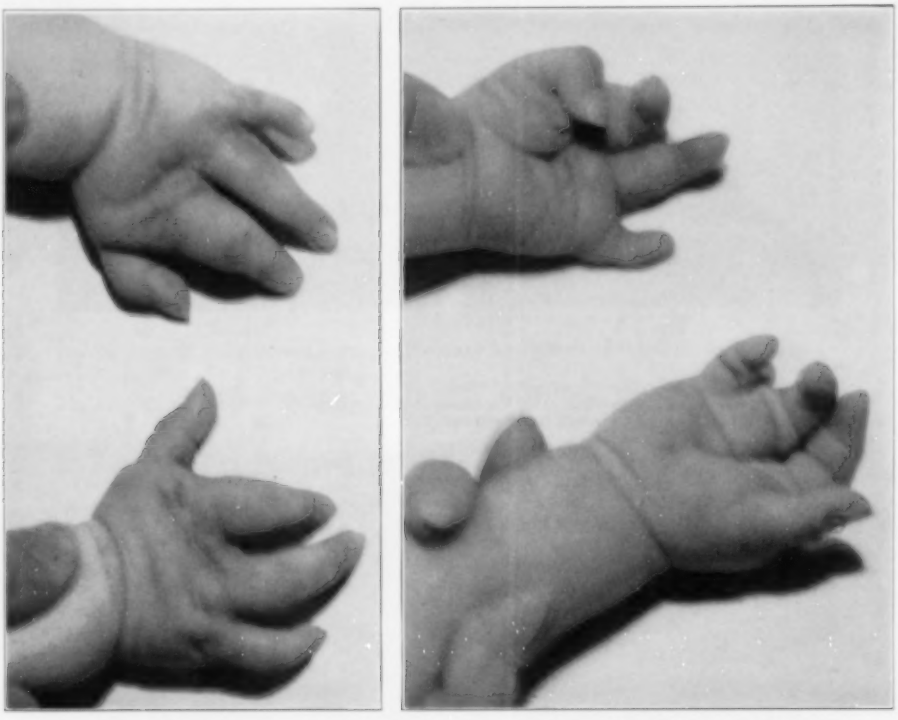

FIG. 6-J FIG. 6-K

Dorsal and volar views of both hands four weeks after surgery. The flexion of the fingers is voluntary.

phalanx of the supernumerary finger. This epiphysis should be found and removed, for if it is not removed, it may grow, causing a hard unsightly swelling.

In some cases in which there are more than five fingers, it is difficult to determine which of the fingers is extra. In these cases surgery may have to be delayed until the proximal epiphyses of the basal phalanges can be seen roentgenographically. The growth center of the proximal phalanx of the supernumerary digit is located to one side of the head of the supporting metacarpal and is smaller than those of the other fingers. Other distinguishing characteristics of the extra digit are that it is often flail and attached by a soft-tissue stalk and that, even if it appears normal, it usually has less muscular control and less mobility than its neighbors.

Treatment of Palmar Cleft

A split in the palm of the hand is frequently accompanied by the absence of one or more fingers; at times two of the remaining digits are partly confluent.

Repair of the split in the palm is obtained in the following manner (Figs. 6-A through 6-K). A rectangular flap of skin, the pedicle of which is level with the web space of the existing fingers, is fashioned from either of the parietes of the cleft. This flap is turned distally so that it bridges the gap near the bases of the divergent digits, thus forming a

FIG. 7-A

FIG. 7-B

Figs. 7-A through 7-D: The means used to obtain simple side-to-side pinch in a seven-year-old girl with no fingers.
Fig. 7-A: Roentgenogram of the hand before surgery.
Fig. 7-B: Roentgenogram made after the bases of the three middle metacarpals and portions of the corresponding carpal bones had been resected.

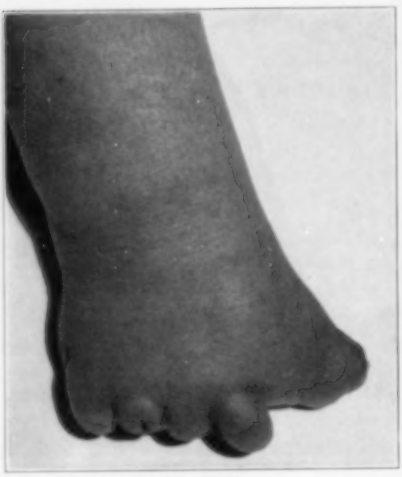

FIG. 7-C

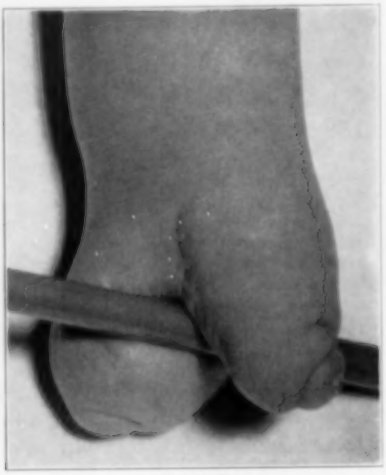

FIG. 7-D

Fig. 7-C: Photograph made before a cleft had been deepened to form two "fingers."
Fig. 7-D: The hand holding a pencil by means of side-to-side pinch.

web. The remaining skin of the cleft is trimmed away, and the palmar and dorsal edges are approximated. Occasionally the palmar cleft cannot be completely removed by one operation, and sometimes a groove deepens along the suture line following the operation. In these cases, secondary plastic repair may be necessary.

Surgery to Obtain Side-to-Side Pinch

Some babies are born with no hands at all, even the carpal bones being missing; for these patients no remedy is possible. If the carpal bones are present, however, and if there

Figs. 9-A through 9-L: The surgical reconstruction of a congenitally deformed hand in a man twenty-eight years old.
Fig. 9-A: Dorsal view of the hand.
Fig. 9-B: Profile view.
Fig. 9-C: Volar view.

FIG. 8-A

FIG. 8-B

FIG. 8-C

Figs. 8-A through 8-F: The means used to obtain appositional pinch in a seven-year-old girl with two fingers webbed by a broad fold of skin.

Fig. 8-A: Roentgenogram of the hand before surgery.

Fig. 8-B: Volar view of the hand before surgery.

Fig. 8-C: Dorsal view. Note that the nails are parallel (compare with the hand shown in Fig. 1-J).

FIG. 8-D

FIG. 8-E

FIG. 8-F

Fig. 8-D: Roentgenogram made after osteotomy of both metacarpals. Following this operation the metacarpophalangeal joint of the radial finger remained stiff, and the metacarpal head had to be resected.

Figs. 8-E and 8-F: Volar and dorsal views showing the functional results. Good appositional pinch was obtained.

FIG. 9-A

FIG. 9-B

FIG. 9-C

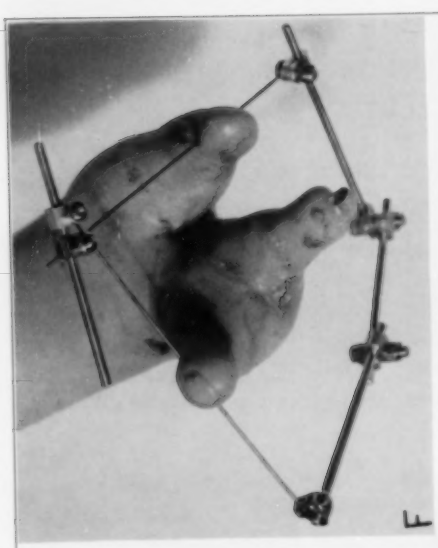

Fig. 9-I

Fig. 9-H

Fig. 9-G

Fig. 9-D: The pedicled graft was sutured to the intermetacarpal cleft which had been surgically deepened between the first and second rays.
Fig. 9-E: The graft was separated from the abdomen and piled on the hand. Later it was readjusted.
Fig. 9-F: The three rays were separated, and the metacarpals of two of the rays were osteotomized and the fingers turned to face one another. Pin fixation was used.
Fig. 9-G: Roentgenogram made before surgery.
Fig. 9-H: Roentgenogram made after resection of the third ray and derotation osteotomy of the first and fifth metacarpals.
Fig. 9-I: Profile view after surgery.

FIG. 9-J

FIG. 9-K

FIG. 9-L

Fig. 9-J: Volar view after surgery.
Figs. 9-K and 9-L: Photographs showing the functional result; pulp-to-pulp pinch has been obtained.

is at least some portion of two of the metacarpal rays, then reconstructive surgery may be attempted. This surgery consists in deepening of the cleft between the two rays and wrapping of these rays separately with skin (Figs. 7-A through 7-D). If the two metacarpals which are at least partially present are the first and the fifth metacarpals, the length of the refashioned stumps may be increased—and their efficiency augmented—by removing the remnants of the second, third, and fourth metacarpals, all of the lesser multangular, and part or all of the capitate.

Surgery to Obtain Appositional Pinch

In a few congenitally deformed hands, the metacarpal of the ring finger is present. In these hands, more efficient appositional pinch may be obtained if the little finger is transferred to this ray.

A deformity sometimes seen is the presence of two small fingers—one on the radial side and one along the ulnar border—which cannot be made to touch because of their insufficient length or because of their divergent alignment. For this deformity the following procedure may be used (Figs. 8-A through 8-F). A definite cleft is obtained by removing the intervening soft tissues—and bones, if necessary—and separately covering the metacarpals supporting the fingers with skin; this gives the digits length. Later, one or both metacarpals may be osteotomized and the fingers turned so that they will face each other. Because the joints have been buried in the web for a considerable length of time and are therefore stiff, the patient may still not be able to make the distal phalangeal pads touch each other to produce pinch. In these cases capsulotomy, arthroplasty, or resection of the metacarpal head may be helpful.

Separation of Confluent Fingers

It is often said that it is best to wait until the patient is four or five years old before separating confluent digits. Actually, however, when two fingers remain connected for a protracted period, the interosseus and lumbrical muscles in the involved cleft atrophy and the joints stiffen. In some cases, a full range of motion can never be obtained after the fingers are separated. Not infrequently syndactylism is accompanied by other anomalies

such as synostosis, absence of the supporting metacarpals and phalanges, absence of tendons, and absence of the thumb or of other fingers. In these cases, surgery to separate the confluent fingers must be coordinated with such other procedures as ostectomy, tendon-grafting, joint resection, osteotomy, and digital shift.

Uncomplicated syndactylism may involve two or more fingers. If only two fingers are confluent and if there are interposed phalanges with no tendons or supporting metacarpals, the interposed bones may be resected and the skin thus made available utilized to cover the adjacent sides of the separated digits. If this skin is not sufficient to cover the denuded areas, however, free grafts may be used—preferably full-thickness grafts obtained from a hairless, thin-skinned area such as is found on the volar aspect of the proximal portion of the forearm or on the inner surfaces of the upper portion of the arm.

The interdigital web space and the adjacent tissues overlying the lumbrical canals are critical areas. It is possible to line these areas with free grafts, and for a time the result of this procedure will be satisfactory; eventually, however, the grafted skin will pucker and contract. Another means to cover these areas is to fashion a flap locally from the dorsum of the adjacent bases of the confluent fingers; this procedure should not be attempted, however, if the flap cannot be brought past the volar ridge of the web space and sutured to the skin of the palm without undue tension.

It is also possible to span the gap by two flaps, a volar and dorsal flap, but in this procedure the suture line will be placed near or at the volar ridge of the web, a region in which it is not desirable to have scarring. In this connection, it is important to consider the growth pattern of the adjacent bones. In the four finger metacarpals the growth center is at the distal end of the bone, while in the phalanges it is at the proximal end; thus, the main growth of the fingers occurs in the region of the web space. As the phalanx is extended forward by growth, it will carry with it the band of scar so that eventually this band will be located far distal to the interdigital web of the unaffected fingers. If the scarred skin overlies the lumbrical canals and binds the tendons of the small intrinsic muscles, the more refined movements of the fingers will be hampered. Because of these considerations we prefer to use pedicled grafts to cover surgical defects in the web space and in the adjacent tissues over the lumbrical canals.

When more than two fingers are confluent, it is not possible to construct sufficient local flaps to cover the involved web spaces without jeopardizing the viability of the intermediary skin. Thus, in these cases, there is even more justification for our preference for pedicled skin grafts. These grafts are obtained from the abdomen and are used to cover almost all the surgically denuded areas. A further justification for the use of pedicled skin grafts is that the various procedures such as osteotomy and ostectomy which are necessary to treat defects frequently associated with multiple syndactylism cannot be safely carried out in the presence of the adherent scar-bound skin which often results from the use of free grafts or local flaps.

When multiple syndactylism is treated late in life, it is not possible to obtain sufficient skin locally even after removal of one or two of the osseous rays. The various other conditions seen in the deformed hands of these older patients include: the tendons are defunct or adherent; the joints are stiff and unbending; the skeletal structure of the hand is defective as to number of bones or their alignment or both; the thumb is missing or confluent and the hand resembles a gnarled knobby rigid paddle. To procure in such hands the function of appositional pinch requires extensive surgery, including ostectomy, joint resection, and derotation or angulation osteotomy. These procedures can best be carried out through pliable skin such as is provided by pedicled grafts (Figs. 9-A through 9-L).

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Experiences with the Use of the Milwaukee Frame in the Treatment of Paralytic Scoliosis*

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From the Georgia Warm Springs Foundation, Warm Springs

The purpose of this paper is to present observations made in the course of a study of 117 patients with paralytic scoliosis who were treated by means of the Milwaukee frame. All the patients were seen at the Georgia Warm Springs Foundation during the period April 1946 to July 1955, and were under the direct supervision of the senior author. The

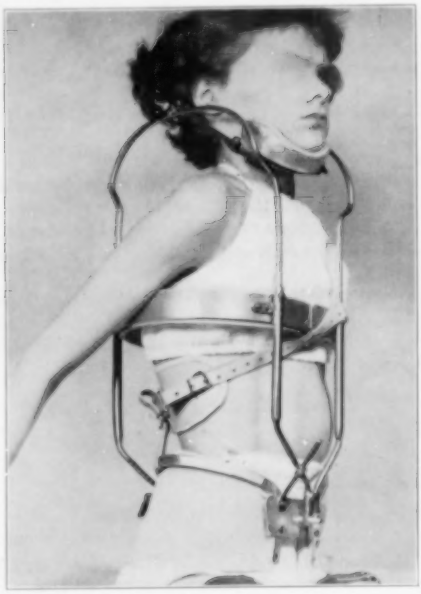

FIG. 1-A

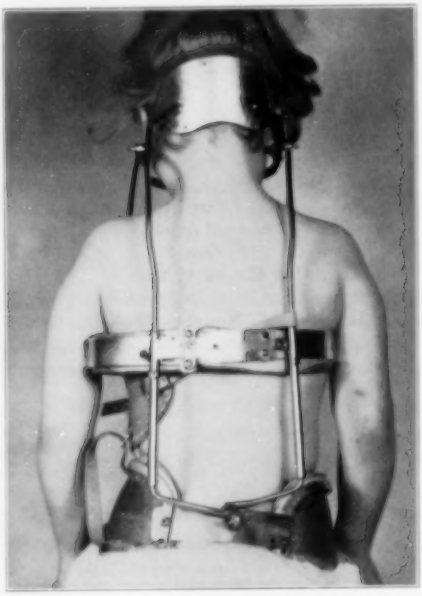

FIG. 1-B

Fig. 1-A: The tilting head piece is comfortable and minimizes chin irritation, and the telescoping uprights allow ready adjustment of the distraction force (the screws are tightened by means of an Allen wrench). The strap-on pressure pad is applied low over the apex of the curve, 45 degrees from the mid-line posteriorly.

Fig. 1-B: The pelvic section is well padded with sponge rubber, and the brace is hinged anteriorly. The posterior locking mechanisms shown here permit easy application and adjustment of the apparatus (the screws are tightened by means of an Allen wrench).

authors feel that the experience gathered from this group of cases justifies the presentation of certain conclusions regarding the value of the Milwaukee frame in the management of paralytic scoliosis.

DESCRIPTION OF BRACE

A brace similar to the original model designed by Blount and Schmidt was first used at the Georgia Warm Springs Foundation in April 1946[1,2]. The present model used at the Foundation includes the basic features of the earlier apparatus—the head and pelvic

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 29, 1957.

† At the time this paper was written, Dr. Wray was a National Foundation for Infantile Paralysis Fellow in Orthopaedic Surgery on the Duke-Warm Springs Program.

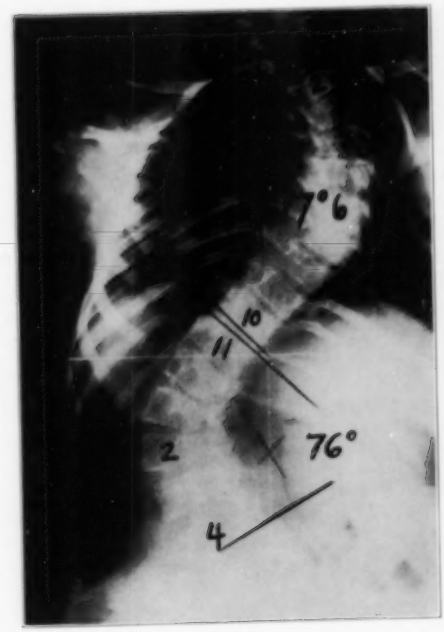

FIG. 2-A

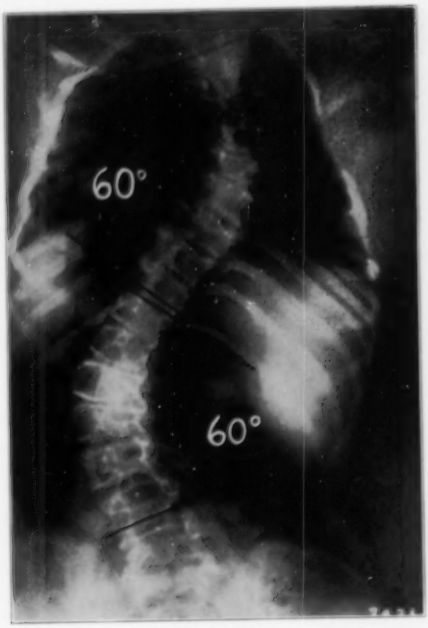

FIG. 2-B

Fig. 2-A: The curve in the thoracic region was 77 degrees and the curve in the lumbar region was 76 degrees when the Milwaukee frame was applied as a conservative corrective apparatus. At that time the patient was nine years of age.

Figs. 2-B and 2-C: Four years after the Milwaukee frame was first applied, the scoliosis measured 60 degrees in the thoracic region and 60 degrees in the lumbar region. The clinical appearance of the back was excellent.

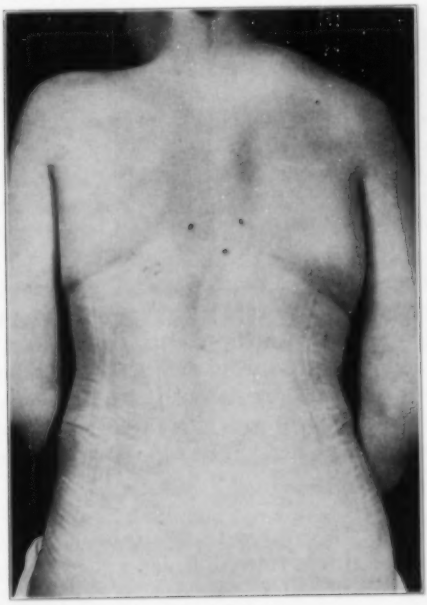

FIG. 2-C

FIG. 2-D

Fig. 2-D: This patient had the most severe overbite encountered in the series. For four years continuous traction was applied for twelve hours daily by means of the Milwaukee frame, a reinforced corset with head traction being used the remaining twelve hours.

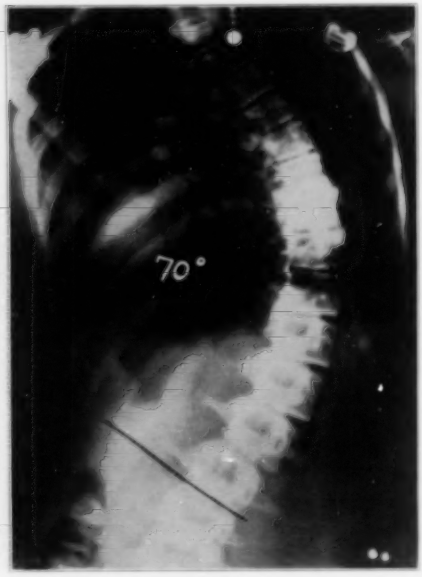

FIG. 3-A

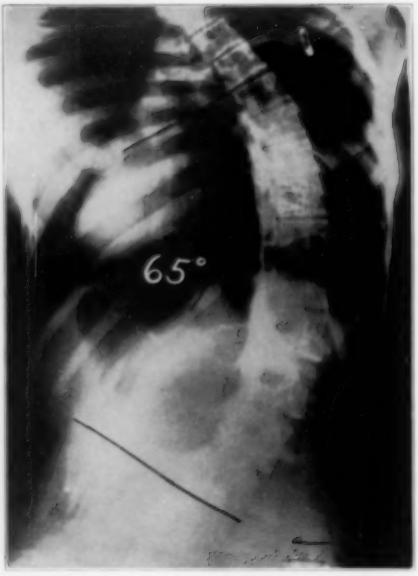

FIG. 3-B

Fig. 3-A: This 70-degree rigid C curve had previously been treated by wedging with unsuccessful results. The patient could not tolerate the respiratory difficulty produced and no correction had been accomplished.

Fig. 3-B: Surgical fusion was performed and the Milwaukee frame was used to obtain postoperative fixation. The final curvature was 65 degrees.

pieces and a pad for the application of lateral pressure—but differs in certain details. In general, the changes have simplified the task of the bracemaker and have increased the comfort of the patient (Figs. 1-A and 1-B).

Replacement of the original fixed chin piece with a tilting chin piece has resulted in greater comfort with much less skin irritation.

The distraction force may be increased at will by adjusting the telescoping uprights. Maximum distraction is easily maintained in the presence of rapid growth without alteration of the brace. The thoracic band serves only to stabilize the uprights and contact with the body is neither essential nor sought.

The fixed pad has been replaced by a strap-on pad to provide lateral pressure. It is applied low at the apex of the curve, 45 degrees from the mid-line posteriorly. In our experience, pressure must be transmitted by way of the ribs to be effective.

The well padded pelvic section can be adjusted in order to accommodate minor degrees of pelvic obliquity and to relieve pressure on the iliac crest or spine. After the brace has been applied with the patient in the supine position, the patient is turned on his side to permit snug adjustment of the posterior locking mechanism. The adjustable lock permits accommodation for moderate increases in size.

SELECTION OF PATIENTS

The Milwaukee frame was employed in this series in three different ways: (1) as a conservative means to obtain corrections, (2) as a substitute for fusion when it was thought that the patient could not tolerate major surgery, and (3) as a means of postoperative fixation following spine fusion.

The apparatus was employed as a conservative corrective apparatus in seventy-four

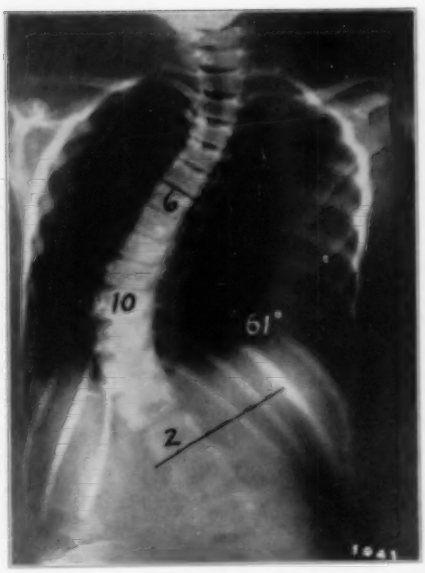

FIG. 4-A

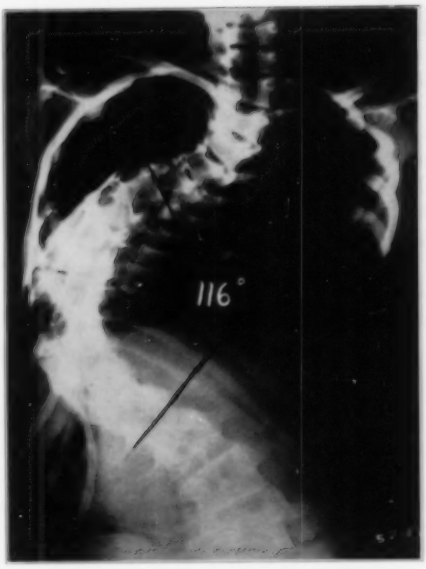

FIG. 4-B

Fig. 4-A: This progressing thoracolumbar curve measured 61 degrees when the frame was applied as a conservative corrective apparatus when the patient was eight and one-half years of age.

Fig. 4-B: Two years and ten months later the curve had progressed to 116 degrees in spite of the most conscientious use of the Milwaukee frame. Fusion was done when the patient was twelve years of age. The scoliosis measured 105 degrees at the completion of all treatment.

patients with progressing curves. The average age of these patients at the time of application was eleven years. Fifty-four (73 per cent) of this group had been treated for varying lengths of time by other types of apparatus, including reinforced corsets and braces of the Barr-Buschenfeldt type. None of these patients was considered a candidate for surgery at the time the apparatus was applied. With our present tendency to perform fusion earlier and more often, however, it is likely that in several of the cases the initial treatment today would be fusion. Table I indicates the types of curves encountered in this and the other groups.

In twenty-one instances the frame was applied to patients whose curves were considered severe enough to warrant fusion at the outset but whose poor general condition seemed to contra-indicate surgery. The average age of these patients was 12.2 years. Many of this group would be treated by fusion today, as present anaesthetic techniques permit surgery in all but very few cases.

The brace was used as a postoperative corrective and holding apparatus in twenty-two patients whose average age was fifteen years. In all of this group the thoracic component of the scoliosis was predominant.

Age did not play a determining role in the selection of patients for treatment. The youngest patient in the entire series was four and one-half years of age. The oldest was twenty-eight when the Milwaukee frame was applied as a means of postoperative fixation following spine fusion.

In contrast to the insignificance of the age factor, the cooperation of both patient and parents proved to be of considerable importance. This factor is particularly vital in out-patient care. It is significant that with the accumulation of experience in this series, the number of uncooperative patients dropped markedly.

TABLE I

TOTAL SERIES

(117 Patients)

Type of Use	No. of Cases	Average Age When Applied (*Years*)	Type of Curve: Cervicothoracic (*No.*)	Thoracic (*No.*)	Thoracolumbar (*No.*)	Double (*No.*)	Lumbar (*No.*)
Conservative corrective apparatus	74 (63%)	11	2	18	26	25	3
Conservative corrective apparatus in cases in which surgery was indicated but not feasible	21 (18%)	12	1	10	7	2	1
Postoperative corrective and holding device	22 (19%)	15		11	7	4	
Totals	117		3 (3%)	39 (33%)	40 (34%)	31 (26%)	4 (3%)

TABLE II

RESULTS IN THE CASES SUITABLE FOR EVALUATION

(82 Patients)

Type of Use	No. of Cases	Average Curve at Start of Treatment (*Degrees*)	Decrease of 10 Degrees or More (*No.*)	(*Per Cent*)	Less than 10 Degrees of Change (*No.*)	(*Per Cent*)	Increase of 10 to 20 Degrees (*No.*)	(*Per Cent*)	Increase of Greater than 20 Degrees (*No.*)	(*Per Cent*)
Conservative corrective apparatus	42	58	8	19	26	62	1	2	7	17
Conservative corrective apparatus in cases in which surgery was indicated but not feasible	18	72	1	6	4	22	6	33	7	39
Postoperative fixation following spine fusion	22	67	12	55	10	45				
Totals	82		21	26	40	49	7	9	14	17

TREATMENT PROGRAM

Patients wearing the apparatus were kept in the reclining position only. Our experience would indicate that the maximal corrective force is poorly tolerated by the erect patient. The uprights were lengthened daily to the limits of tolerance. Care was taken to see that the patient became accommodated to the apparatus preoperatively. The frame was placed on the patient while he was on the operating table, and the removable head piece was applied after he had recovered from the anaesthesia.

When used on patients in the hospital, the frame was maintained postoperatively on a twenty-four hour basis for an average of six months and then was usually continued on a part-time basis for varying periods. When used as a conservative holding apparatus in out-patient care, however, the frame was maintained for a twelve-hour period each day, other types of apparatus being employed for support of the trunk during the remaining twelve hours. Before discharge to out-patient care both patient and parents were thoroughly instructed in the use of the frame.

RESULTS

Twenty-two of the original 117 cases were discarded because of inadequate follow-up, and thirteen more were excluded because of lack of cooperation by the patient or parents in the treatment program. Table II outlines the results in the remaining eighty-two cases that were found suitable for evaluation.

Forty-two of the cases in which the frame was used as a conservative corrective apparatus were eligible for evaluation. The curves in these cases averaged 58 degrees when the frame was applied. The treatment program lasted for from one to six years, the average period being two years and seven months. Eight curves improved by 10 degrees or more (Figs. 2-A, 2-B, and 2-C); twenty-six showed a change of less than 10 degrees; one increased 13 degrees; and seven increased more than 20 degrees.

In the eighteen cases available for evaluation in which fusion was indicated but considered prohibitively dangerous, the brace was less successful. Curves in this group averaged 72 degrees before the brace was applied. The length of treatment ranged from one to six years with an average duration of two years and two months. Only one curve improved 10 degrees or more, and four showed less than 10 degrees of change; six curves progressed from 10 to 20 degrees, and seven increased more than 20 degrees.

All the original twenty-two cases in which the Milwaukee frame was used for postoperative immobilization following spine fusion were suitable for study. The average preoperative curve in these cases measured 67 degrees. The apparatus was usually worn on a full-time basis for six months postoperatively and then on a part-time basis for varying lengths of time. In twelve instances 10 degrees or more of improvement was obtained, while the remaining patients showed less than 10 degrees of change.

DISCUSSION

Use of the Milwaukee frame possesses certain advantages over the corrective-plaster techniques. Many patients with severe paralytic scoliosis do not tolerate wedging of the thoracic spine well. It seems likely that correction by means of a pressure pad combined with distraction is as effective as wedging in these cases, and certainly it has not proved nearly so detrimental to the respiratory exchange. In addition, the apparatus has proved highly effective as a holding and corrective device for severe curves after fusion (Figs. 3-A and 3-B). Breakdown of the skin which may result from the use of a rigid enclosing apparatus in a severely emaciated patient has not occurred with the Milwaukee frame.

The expenditure of time and labor necessary for plaster correction may be prohibitive in a hospital with a small staff handling a large number of patients with severe scoliosis. Management by means of the Milwaukee frame lends itself to frequent brief visits that allow the surgeon to follow the cases more closely.

The brace has limitations as well as advantages. It is apparent that use of the apparatus will not replace spine fusion in the management of scoliosis (Figs. 4-A and 4-B). The poorest results in this series were obtained in patients who were considered too young for spine fusion or whose respiratory status was thought to be too inadequate. Partially on the basis of the findings presented here, the authors now tend to perform fusion earlier and rarely withhold the procedure because of limited respiratory reserve.

We do not consider the apparatus an appropriate means of treatment for the average lumbar curve. In the four cases in which the apparatus was applied to a lumbar curve, the marked foreshortening of the trunk was the determining factor. In the few cases in which the frame was applied in the presence of a severe pelvic obliquity, the results were uniformly unsuccessful and have not been included in this report. In the several cases in which the pelvic obliquity was first surgically corrected, however, the curves responded well to treatment by the Milwaukee frame.

Complications were rare and of little significance. A mild overbite developed in six patients after they had worn the frame for an average of three and one-half years. In all these cases the supplementary apparatus used to obtain head traction subjected the patient to chin pressure for twenty-four hours of the day. The most severe of these cases is shown in Figure 2-D. In two cases mild pressure areas developed over the ilia. These lesions responded to routine care without interruption of the treatment program. Dermatitis of the chin was a rather frequent occurrence before the introduction of the tilting head section. It is now rarely seen.

CONCLUSIONS

1. The Milwaukee frame permits the surgeon to apply traction and lateral-pressure corrective forces to the scoliosis with a minimum of effect upon the respiratory exchange. It is comfortable and has several advantages over plaster treatment in certain types of scoliosis.

2. The apparatus has been successful in halting curve progression in 81 per cent of the forty-two cases available for evaluation in which surgery was not deemed necessary at the outset of treatment. On the other hand, it has not been found an adequate replacement for fusion in the management of the severely degenerating curve.

3. The Milwaukee frame has been very effective as a holding and correcting apparatus for thoracic curves following fusion.

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2. Campbell's Operative Orthopedics. Ed. 2, pp. 1548–1549. Edited by J. S. Speed and Hugh Smith. St. Louis, The C. V. Mosby Co., 1949.

Treatment of Grade IV Fracture-Dislocation of the Hip

A Review *

BY GARRETT PIPKIN, M.D., KANSAS CITY, MISSOURI

This review deals with Grade IV fracture-dislocation of the hip, which is defined by Stewart and Milford as dislocation of the hip with fracture of the head or neck of the femur. This was originally a rare injury which occurred largely in heavy industry. It is now apparently becoming more common as a result of modern traffic accidents. It is still unusual, however, and only occasional cases have been reported. Summaries of the known cases were published in 1926 and 1934[5,7]. Few textbooks on fractures even mention this injury.

MATERIAL

The material for this analysis represents the pooled experience of a Correspondence Club and of the orthopaedic surgeons of Greater Kansas City †. The series includes a total of twenty-five hips in twenty-four patients, with follow-ups of one to eighteen years.

The material consists of serial roentgenograms and case histories with end-result evaluations by the contributing surgeons (Table I). Most of the cases considered have been well documented and kept in teaching files, but only seven of the patients have been examined clinically by the author. Obviously, such an analysis is open to criticism. Some pertinent comments with regard to this type of study are Bank's statement that, "No one surgeon will accumulate a series of cases sufficiently large to answer some of the problems which result from this injury . . .," and Thompson and Epstein's remarks that, "A statistical analysis requires a minimal number of cases . . . before a probability determination can be made. . . . Surgeons with an understanding of the reactions of the joint to trauma may arrive at a correct conclusion before a significant [statistical] comparison can be made."

Classification of Injuries

According to Stewart and Milford, there are four grades of fracture-dislocation of the hip. Grades I, II, and III are described as dislocation of the hip with varying degrees of injury to the acetabular rim, while, as previously mentioned, Grade IV is described as dislocation of the hip with fracture of the head or neck of the femur. Since Grades I, II, and III have been well discussed in the current literature[1,3,6,8-10], this review will adhere strictly to the problems peculiar to Grade IV injuries.

For purposes of analysis it has been deemed advisable to divide Grade IV fracture-dislocations into the following types:

Type 1: dislocation with fracture of the femoral head caudad to the fovea capitis femoris (Fig. 1-A).

Type 2: dislocation with fracture of the femoral head cephalad to the fovea capitis femoris (Fig. 1-B).

Type 3: type 1 or type 2 injury associated with fracture of the femoral neck (Fig. 1-C).

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 30, 1956.

† Surgeons contributing cases to this review were: R. H. Fitzgerald, Independence, Missouri; C. L. Francisco, Kansas City, Kansas; H. A. Hamel, Kansas City, Missouri; L. J. Iglesias, Havana, Cuba; O. E. James, Jr., Kansas City, Missouri; E. D. McBride, Oklahoma City, Oklahoma; Spencer McCrae, Salina, Kansas; W. H. McGaw, Cleveland, Ohio; D. C. McKeever, Houston, Texas; J. T. Nicholson, Philadelphia, Pennsylvania; P. C. Nohe, Kansas City, Kansas; J. C. Pickett, Morgantown, West Virginia; Garrett Pipkin, Kansas City, Missouri; J. H. G. Robertson, Salisbury, South Rhodesia; Lyman Smith, Elgin, Illinois; and R. Van Cauwenberghe, Liege, Belgium.

TABLE I

Case No.	Name of Reporting Surgeon	Length of Follow-up	Mode of Injury	Age (*Years*)	Sex	Type	Primary Treatment	Secondary Treatment	Comments	Grade
1	Iglesias	4 yrs.	Auto	31	M	1	Closed reduction		Bone union; able to return to full military duty	Good
2	Iglesias	2½ yrs.	Auto	29	M	2	Closed reduction		Traumatic arthritis after two years	Fair
3	Iglesias	2 yrs.*	Auto				Closed reduction		Bone union	Good
4	Iglesias	2 yrs.*	Auto				Closed reduction		Bone union	Good
5	McGaw	5 yrs.	Auto	50	M	2	Closed reduction		Bone union; able to play 27 holes of golf	Good
6	Francisco	4 yrs.*	Railroad	58	M	4	Closed reduction		Bone union; returned to railroad section work	Good
7	Fitzgerald	7 yrs.	Auto	30	M	1	Closed reduction	Delayed excision lesser fragment	Unlimited weight-bearing	Good
8	Pickett	4 days	Auto	36	F	2	Closed reduction		Surgical fracture; death (patient had multiple assoc. injuries)	
9	Pipkin	6 yrs.	Auto	63	M	2	Attempted closed reduction; immediate insertion endoprosthesis		Surgical fracture occurred during attempted closed reduction	Serviceable
10	McBride	2 yrs.	Auto	35 (about)	M	1	Two attempts at closed reduction	Open reduction and excision lesser fragment; 14 mos. later, insertion endoprosthesis for avascular necrosis		Serviceable
11	McGaw	1 yr.	Auto	40	M	3	Closed reduction; immediate Whitman reconstruction			Serviceable
12	Francisco Pipkin Nohe	4 yrs.	Auto	65	M	4	Closed reduction	Insertion endoprosthesis at 4 mos.; insertion different type at 6 mos.	Surgical infection; still on crutches; further surgery necessary	Failure

13	McKeever	4 yrs.	Auto	55	F	3	Open reduction; internal fixation subtrochanteric fracture	Intramedullary nailing subtrochanteric fracture after fracture of angle plate	Normal household activity without crutches or cane	Good
14	McKeever	(Same patient as in Case 13)				2	Primary insertion endoprosthesis			Serviceable
15	Robertson	2 yrs.	Auto	30 (about)	M	2	3 attempts closed reduction; open reduction		Returned to job as Army truck driver	Good
16	Pipkin	18 yrs.	Auto	38	F	2	Open reduction and internal fixation		Painless weight-bearing for 17 yrs.; then pain and loss of motion due to degenerative changes	Good
17	Nicholson	9 yrs.	Auto	41	M	3	Open reduction and internal fixation		Spontaneous ankylosis 3½ yrs. later	Serviceable
18	Pipkin	2½ yrs.	Auto	46	M	2	Open reduction and internal fixation	Insertion endoprosthesis for fatigue fracture of femoral neck at 4 mos.	Painless weight-bearing; cane for balance	Serviceable
19	Pickett	14 yrs.	Falling tree		M	3	Open reduction and nailing femoral-neck fracture		Spontaneous ankylosis 14 yrs. later	Serviceable
20	Van Cauwenberghe	3 yrs.	Auto	47	M	2	Attempted closed reduction and traction; open reduction and excision lesser fragment		Spontaneous ankylosis 3 yrs. later	Serviceable
21	James	24 mos.	Auto	55	F	1	Open reduction and excision comminuted lesser fragments		Still under observation	Serviceable
22	Hamel	3 yrs.	Auto	36	M	1	Open reduction and excision comminuted lesser fragments		Extensive avascular necrosis; will require further surgery	Failure
23	McCrae *	Lost	Auto	20	M	1	Open reduction and excision lesser frag.		Army case; limited follow-up	Reported serviceable
24	Smith	30 mos.	Auto	30 (about)	M	4	Open reduction and excision lesser frag.		Spontaneous ankylosis	Serviceable
25	Pickett	3 yrs.	Auto	26	M	1	Two attempts at closed reduction; open reduction and excision lesser frag.		Still under observation	Serviceable

* The follow-up data are based on verbal reports, additional roentgenograms not being available.

FIG. 1-A

FIG. 1-B

Fig. 1-A: Type 1 fracture-dislocation of the hip: dislocation with fracture of the femoral head caudad to the fovea capitis. The head fragment is small.

Fig. 1-B: Type 2 fracture-dislocation of the hip: dislocation with fracture of the femoral head cephalad to the fovea capitis. The head fragment is large.

FIG. 1-C

FIG. 1-D

Fig. 1-C: Type 3 fracture-dislocation of the hip: dislocation, fracture of the femoral head, and fracture of the femoral neck.

Fig. 1-D: Type 4 fracture-dislocation of the hip: dislocation, fracture of the femoral neck, and fracture of the acetabular rim.

Type 4: type 1 or type 2 injury associated with fracture of the acetabular rim (Fig. 1-D).

Classification of Results

The nature of the injury precludes any results being graded as *excellent* on the basis

FIG. 2

A laterally rotated fragment may block reduction.

of the standards outlined by Thompson and Epstein. The grade *good* has been given to hips which are painless, can tolerate weight-bearing, and have only a few degrees of limitation of motion and minimal roentgenographic changes. The grade *serviceable* has been given to hips which are able to tolerate weight-bearing but are still under observation because of incongruity and to hips in which successful salvage procedures have been done. *Failure* has been the grade given all other results.

Preparation of the Illustrations

Many of the roentgenograms shown in this paper, particularly those made upon admission of the patient to the hospital, are of poor quality. In most cases the patient had sustained multiple injuries in addition to fracture-dislocation of the hip, and for this reason the surgeon did not feel justified in having additional roentgenograms made merely in order to obtain teaching material. Post-reduction roentgenograms were frequently made by means of portable units, and in some instances they were taken through plaster-of-Paris casts. Because of these difficulties the author prepared some of his illustrations with the help of an artist, his purpose being to bring out the salient points by means of contact prints.

TREATMENT OF TYPE 1 AND TYPE 2 FRACTURE-DISLOCATIONS

Closed Reduction

A division is made on the basis of whether the fracture occurs above or below the fovea capitis femoris because of the mechanism of the ligamentum teres femoris. If the ligamentum teres remains attached to the lesser fragment, that fragment may be rotated as the hip dislocates, with the result that it faces laterally. Unless the fragment can be derotated, closed reduction cannot be accomplished (Fig. 2).

Good management depends upon prompt reduction of the dislocation. Bone union is

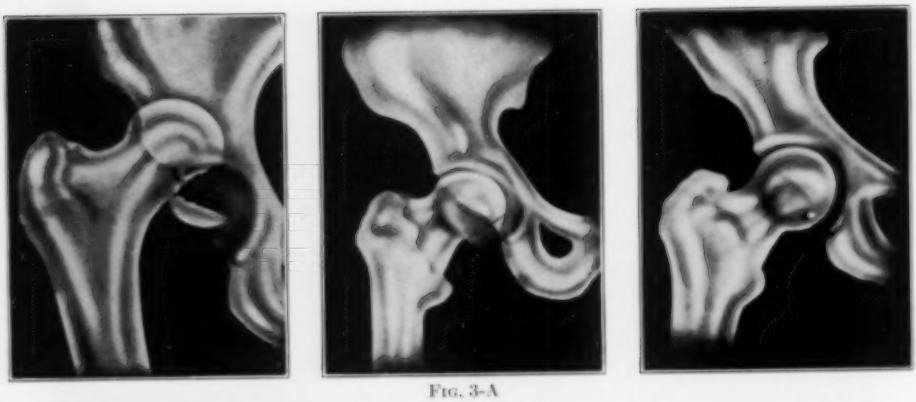

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 1 (courtesy L. J. Iglesias). Drawings showing a type I fracture-dislocation treated by closed reduction. *Left:* the preoperative condition. *Center:* the operative condition. *Right:* the end result.

Fig. 3-B: Preoperative roentgenogram showing the dislocation and the small fractured head fragment.

Fig. 3-C: Postoperative roentgenogram.

Fig. 3-D: Roentgenogram showing the end result.

FIG. 3-C

FIG. 3-D

FIG. 4-A

FIG. 4-B

Figs. 4-A through 4-D: Case 2 (courtesy L. J. Iglesias). Type 2 fracture-dislocation treated by closed reduction.

Fig. 4-A: Preoperative roentgenogram showing the dislocation and the large fractured fragment of the femoral head.

Fig. 4-B: Postoperative roentgenogram

FIG. 4-C

FIG. 4-D

Fig. 4-C: Bone union was obtained by four months after the operation.

Fig. 4-D: Degenerative changes developed by two years after the trauma. The hip could still tolerate weight-bearing and had good motion. The result was considered fair.

obtained in types 1 and 2 if closed reduction is done and the limb is then immobilized in traction or plaster of Paris for several months (Figs. 3-A through 4-D).

Since the smaller detached fragment usually functions in the securing of congruity rather than in weight-bearing, the subsequent presence of degenerative changes in this fragment does not affect hip function as much as would the loss of this fragment.

The cephalad fragment, which fortunately constitutes the weight-bearing portion of the femoral head, remains attached to the femoral neck, so that its circulation has a reasonable chance for survival. The results of early successful closed reduction in this fracture

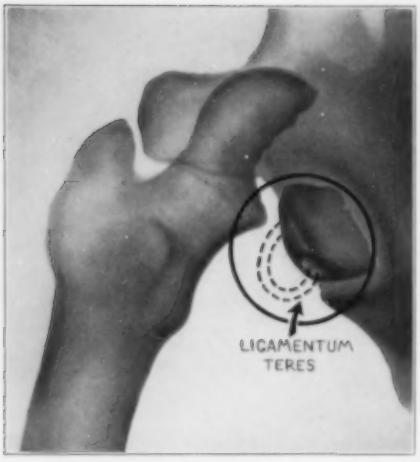

FIG. 5-A

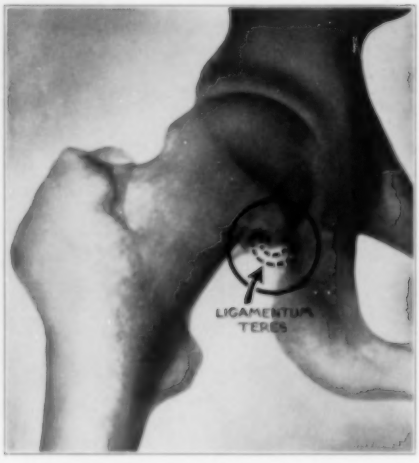

FIG. 5-B

Case 5 (courtesy W. H. McGaw). Upside-down reduction; note the position of the fovea capitis.

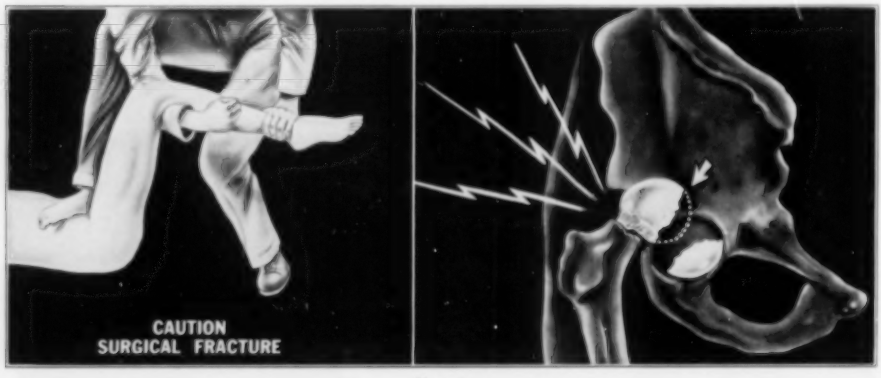

FIG. 6

Fracture may occur during an attempt to obtain closed reduction.

should be about the same as those in the average uncomplicated traumatic posterior dislocation of the hip. The results of closed reduction in this series are presented in Table I.

The reduction of the femoral-head fracture need not be anatomically complete. Since the lesser fragment is a portion of a sphere, it is theoretically possible for this fragment to be shaped in such a way that reduction may be obtained with the fragment rotated as much as 180 degrees. Case 5 illustrates this point.

CASE 5. Closed reduction was obtained with the lesser fragment rotated so that the fovea capitis lay on the femoral neck (upside-down reduction) (Figs. 5-A and 5-B). Apparently the important point was that hip congruity was maintained. Bone union of the fracture resulted, and three years later the result was classed as *good*. This patient is now fifty-three years of age, and the excellence of the functional result may be judged by the fact that he is able to play twenty-seven holes of golf in one day without pain.

Fracture may occur during an attempt to perform closed reduction (Fig. 6). From reported descriptions of this complication, it appears that it has occurred when the surgeon levered the already weakened femoral neck against the iliac rim. Stimson's gravitational method would appear to be the method of choice.

Surgical fracture occurred in two patients in this series (Cases 8 and 9). One of

FIG. 7-A

FIG. 7-B

Case 16. Anteroposterior and lateral roentgenograms showing the result seventeen years after treatment by open reduction and internal fixation. At this time the hip was able to bear weight without pain. During the next year degenerative changes developed in the lesser fragment.

FIG. 8-A

FIG. 8-B

Case 7 (courtesy R. H. Fitzgerald). Anteroposterior and lateral roentgenograms made five years after treatment by immediate closed reduction and subsequent excision of the lesser fragment. This hip was able to bear weight without pain.

these patients (Case 8) later died, the only fatality in the series. This patient had sustained severe head and chest injuries at the time of the accident.

Open Reduction

Operation is indicated when closed methods have failed as a result of (1) the presence of an obstructive fragment, (2) inability to obtain and maintain reduction of either the dislocation or fracture or of both, and (3) comminution of the fractured bone. The operative procedures used in this series have included: (1) open reduction of both the

fracture and the dislocation, (2) open reduction of the dislocation after internal fixation of the fracture, (3) closed reduction and subsequent excision of the lesser fragment, (4) open reduction after excision of the lesser fragment, and (5) salvage procedures.

There is a higher percentage of failures following open operation than there is following successful closed reduction. The factors involved in this higher percentage are multiple and include previous unsuccessful attempts at closed reduction, delay in obtaining reduction, and the occurrence of surgical trauma, which may happen regardless of how skillfully the surgery is performed.

Bone union and good long-term function have resulted following use of open reduction and suitable immobilization in type 1 and type 2 fractures. In these fractures the femoral-

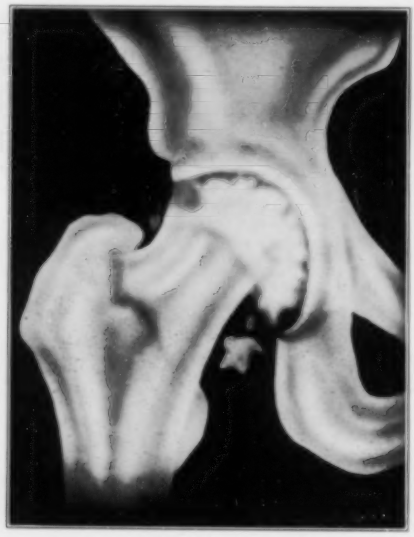

FIG. 9-A

FIG. 9-B

Fig. 9-A: Case 10 (courtesy E. D. McBride). There was rapid degeneration of the head of the femur fourteen months after the excision of a blocking fragment.
Fig. 9-B: Salvage was obtained by means of an endoprosthesis.

head fragments may "mesh" together, resulting in restoration of congruity. Use of internal fixation is practical in type 2 fractures in which there is a single fragment.

In two patients with type 2 fractures, use of internal fixation obtained an immediate excellent result. In these patients two screws were inserted through the fovea capitis into the base of the femoral neck in order to maintain the reduction of the fracture. The dislocation was then reduced. One patient (Case 16) continued to have an excellent functional result for seventeen years (Figs. 7-A and 7-B), after which time pain and some loss of motion developed as a result of degenerative changes in the lesser fragment. In the other patient (Case 18) a fatigue fracture of the femoral neck occurred four months after the operation. Salvage was obtained by means of an endoprosthesis.

In Case 7, closed reduction and the subsequent excision of an incongruous lesser fragment resulted in one of the best results in this series (Figs. 8-A and 8-B). This is in line with the established principles of treatment of traumatic hip dislocation, that is, that prompt closed reduction should be carried out even though comminution of the minor fragments indicates the necessity of their surgical removal at a later date.

In some cases, open reduction of the dislocation can be accomplished only following excision of the blocking fragment. An acceptable functional result is usually obtained by

FIG. 10-A

FIG. 10-B

Case 20 (courtesy R. Van Cauwenberghe). Anteroposterior and lateral roentgenograms showing the presence of bony ankylosis three years after open reduction and excision of a blocking fragment.

FIG. 11-A

FIG. 11-B

Fig. 11-A: Case 13 (courtesy D. C. McKeever). Preoperative roentgenograms showing the Grade IV, type 3 fracture-dislocation of the hip.
Fig. 11-B: Roentgenogram made three years after revision by means of an intramedullary nail. A painless weight-tolerant hip resulted.

this means in type 1 fractures in which the fragment is small. As the size of the lesser fragment increases, its excision causes increasing hip incongruity, resulting in progressive degenerative change. Case 10 illustrates this point.

CASE 10. The hip continued unstable after two attempts at closed reduction. Fourteen months after removal of a blocking fragment and open reduction, extensive degenerative changes were apparent (Fig. 9-A). Salvage was obtained by means of an endoprosthesis (Fig. 9-B). The result was serviceable.

The surgeons submitting Cases 21, 22, 23, 24, and 25 had treated the injury by open reduction following excision of a blocking or comminuted lesser fragment. They

all agreed (1) that the immediate functional result of this treatment was surprisingly good and (2) that the resulting incongruity of the hip made the future development of traumatic arthritis probable and that, therefore, long-term follow-up was necessary.

In three cases fibrous or bony ankylosis developed. The end results of Cases 17, 19, and 20 are all similar. The surgeons reporting these cases performed some form of open reduction. After the operation the patients had hip motion for variable periods of time. This motion decreased as peri-articular calcification became manifest, and in three to five years after the operation the calcification was so extensive that all motion was blocked except for a few degrees of flexion and extension. This amount of motion was quite useful to the patient in changing from the sitting to the standing position. The hips were weight-tolerant with minimal or no pain. Thus, increasing peri-articular calcification and decreasing joint motion are not indications for further joint surgery. An acceptable partial ankylosis may develop spontaneously.

Case 20. The injury in this case was a type 2 fracture-dislocation with a blocking fragment. Several attempts at closed reduction failed; an attempt to obtain reduction by skeletal traction also failed. Firm reduction of the dislocation was finally obtained by open reduction following excision of the lesser fragment. During the subsequent three years progressive peri-articular calcification resulted in ankylosis of the hip. The status of the hip at the end of this time was as follows:

Pain: The patient had no pain while working. He had returned to his former occupation (contractor-mason), and despite the fact that he was on his feet all day, his only complaint in the evening was that he was somewhat tired.

Mobility: There was almost complete ankylosis with the hip in 25 degrees of flexion, slight abduction, and 45 degrees of external rotation. The range of motion of the knee was from 70 degrees to 180 degrees. There was no Trendelenburg sign.

Roentgenographic findings: The roentgenograms (Figs. 10-A and 10-B) revealed spontaneous arthrodesis with the hip in external rotation and slight flexion.

Another case (Case 17) in which fibrous ankylosis developed is discussed in the section on the treatment of type 3 fractures.

TREATMENT OF TYPE 3 FRACTURE-DISLOCATIONS

There are three elements in the type 3 injury: dislocation of the hip, fracture of the femoral head, and fracture of the femoral neck. The mechanism of this injury includes the application of two forces. The first force produces the dislocation of the hip and the fracture of the femoral head; the second force then levers the dislocated head against the iliac wing so that the femoral neck is fractured. The pattern of this injury has been unintentionally reproduced in surgical fractures.

All three elements of the injury must be reduced. Theoretically, closed reduction is possible, but an open procedure in which the neck fracture is pinned is more practical. This method reduces the problem to that found in type 1 or type 2 injuries. Case 13 illustrates the type of problem that may be encountered in this injury.

Case 13. Both hips in this patient were injured, the fracture-dislocation in the right hip being type 2 (Case 14) and that in the left hip being type 3. The injury in the left hip consisted in dislocation of the hip, fracture of the femoral head, comminuted fracture of the base of the neck, and subtrochanteric fracture (Fig. 11-A). The hip dislocation and femoral-head fracture were treated by open reduction, the fragments of the head being meshed together so that internal fixation was not required. The subtrochanteric fracture was reduced, and the fragments were fixed by means of nails and an angle plate. Four months after the operation, the angle plate fractured. By that time, however, there was bone union of the head and neck fragments, with the result that the subtrochanteric fracture could be revised by means of an intramedullary nail. Bone union was subsequently obtained, and the final result was a hip able to tolerate weight-bearing (Fig. 11-B).

The right hip (Case 14) was treated by means of an endoprosthesis (this injury will be discussed further in the section on salvage procedures). The patient is now able to walk without support and to do her own housework.

Case 17. The type 3 injury in this case (Fig. 12-A) was treated by open reduction. Two small fragments of the head were removed and then reinserted by means of four brads made from short pieces of Kirschner wire; the fragments of the neck fracture were approximated and fixed by a Smith-Petersen nail (Fig. 12-B).

FIG. 12-A

FIG. 12-B

Figs. 12-A through 12-C: Case 17 (courtesy J. T. Nicholson). Type 3 fracture-dislocation treated by open reduction and internal fixation (brads and a nail). Spontaneous ankylosis was present by two and one-half years after the trauma.

Fig. 12-A: Preoperative appearance.

Fig. 12-B: Postoperative appearance.

Plaster immobilization was maintained for seven months after the operation. By three and one-half years after the operation, spontaneous fibrous ankylosis had developed (Fig. 12-C). The result was sufficiently satisfactory for the patient to return to work.

Nine years later the patient was readmitted to the hospital with a comminuted fracture of the shaft of the ipsilateral femur. This injury occurred when the man was struck in the thigh by a flying fragment of wood from the log he was sawing. This fracture was treated by means of skeletal traction. The final result was rated *serviceable*, the limb being able to tolerate weight-bearing.

FIG. 12-C

Fig. 12-C: Appearance after the development of spontaneous ankylosis.

TREATMENT OF TYPE 4 FRACTURE-DISLOCATIONS

There are three elements in type 4 fracture-dislocations: dislocation of the hip, fracture of the femoral head, and fracture of the acetabular rim. Because of the last element this injury also comes under the classification of Grade I, II, or III fracture-dislocation, the specific grade depending upon the degree of involvement of the iliac rim. The pattern of the femoral-head fracture seen in a type 4 injury may be the same as that seen in a type 1, a type 2, or a type 3 injury. Theoretically there are six possible combinations which may be found in this type of injury. When necessary, stability of the acetabulum should be restored by open reduction of the rim fracture. The femoral-head fracture should be treated according to the principles already described. There were three type 4 fracture-dislocations in this series.

CASE 6. The injury in this case was treated by closed reduction; a good result was obtained. Four years later, it was reported that the patient was working on a railroad section gang.

CASE 24. Excision of a blocking fragment was necessary in order to obtain reduction. The fracture of the acetabular rim (Grade I) did not interfere with the stability of the reduction. The immediate functional result was good. When the patient was last seen, two and one-half years later, however, peri-articular calcification was developing and the hip was losing motion, although it was not painful enough to keep the man from his regular occupation as a truck driver.

CASE 12. The hip was unstable as the result of a large fracture of the acetabular rim. Closed reduction was done, but four months later neither stability of the acetabulum nor union of the femoral-head fragments had been obtained. An endoprosthesis was inserted to replace the femoral head, but stability was not obtained and the result was considered unsatisfactory. A second attempt at replacement with a different type of endoprosthesis resulted in surgical infection. The hip is still draining, and a clean-up procedure must be done before any further reconstructive measures can be considered.

SALVAGE PROCEDURES

Three hips in this series were considered to be irreparable and, therefore, were treated by immediate reconstructive procedures. In Case 11 a Whitman reconstruction was performed on the second day following injury. In two hips (Cases 9 and 14) endoprostheses were inserted shortly after the injury. In Case 14 (same patient as Case 13), it was felt that the type 2 fracture-dislocation of the right hip could be treated only by a salvage procedure since the detached fragment composed the weight-bearing portion of the femoral head. The endoprosthesis was inserted three weeks after the trauma.

In two cases in this series (Cases 10 and 18) an endoprosthesis was inserted following failure of operative procedures, and in one other case (Case 12) salvage was attempted following failure of closed reduction.

COMPLICATIONS

The following complications were encountered in this series: (1) surgical fracture of the femoral neck during attempted closed reduction, (2) fatigue fracture of the femoral neck after successful open reduction, (3) avascular necrosis, (4) mechanical incongruity and traumatic arthritis, (5) myositis ossificans of the short rotators, (6) peri-articular calcification, (7) paralysis of the peroneal nerve, (8) surgical infection, and (9) spontaneous fibrous or bony ankylosis.

The majority of these complications are common occurrences in the treatment of traumatic dislocation of the hip and need not be discussed further. The complications peculiar to this injury concerning which comment was deemed advisable have already been discussed.

DISCUSSION

The results in this series are presented in Table I. As already indicated in the discussion of grading, the final result in an injury of this type can never qualify as *excellent* according to the criteria of Thompson and Epstein. In all cases reviewed there was some roentgenographic evidence of degenerative changes which made the highest possible grade that of *good*. The functional results were usually better than the grades would indicate, however. This discrepancy is due to the fact that the degenerative changes which occurred were in the lesser fragment and thus did not involve the weight-bearing portion of the femoral head.

This review covers a series of twenty-five hips seen between 1938 and 1955. The first known case was reported by Birkett in 1869. Henry and Bayumi could find only thirteen recorded cases in their review of the literature in 1934.

About thirty years ago, Christopher wrote with regard to this injury that "the prognosis as to function is extremely grave." The results in this series form a favorable contrast to those reported previously (Chart I). The significant lowering in mortality and the marked increase in satisfactory results are a credit to modern orthopaedic surgery.

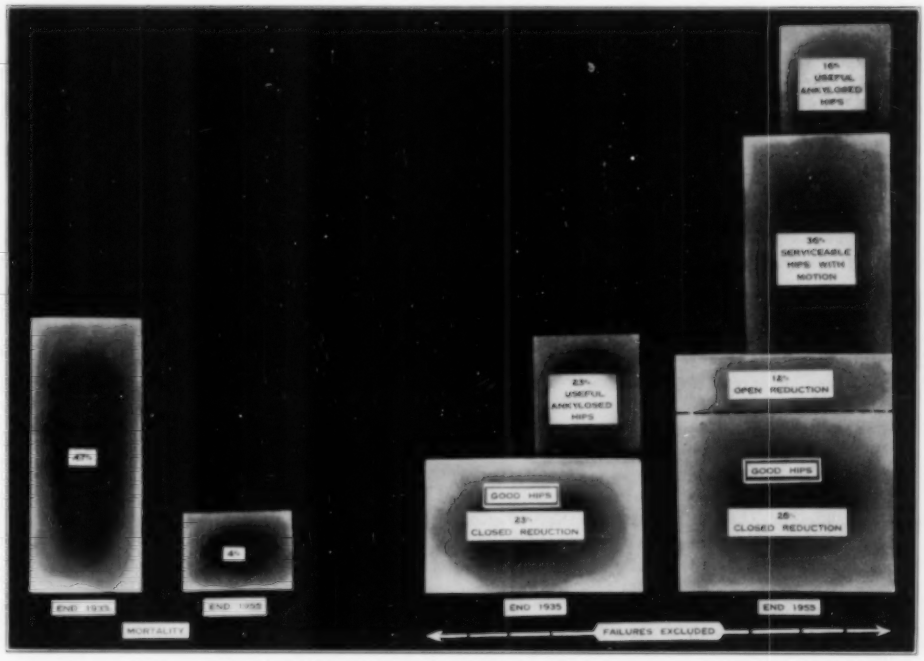

CHART I

Comparison of the results in this series with those in the series reported by Henry and Bayumi.

CONCLUSIONS

1. The best results in this series were achieved by prompt closed reduction followed by traction or immobilization. When this method of treatment was used, bone union of the fracture of the femoral head resulted.

2. In the remaining cases in this series, in which closed reduction could not be successfully done, a small percentage of good results was obtained by open reduction with or without internal fixation.

3. Open reduction after excision of a blocking or comminuted fragment usually resulted in a hip which could tolerate weight-bearing for several years. At present there is not sufficient data on which to base a prediction of the weight-bearing expectancy of such a hip.

4. Salvage procedures are indicated for hips in which there is irreparable immediate damage and for hips in which there is progressive degeneration.

5. The terminology of dislocation and fracture-dislocation of the hip continues confused, although modern English authors are in general accord [1, 3, 9, 10, 11]. Future studies would be facilitated and an indexing of the literature would be simplified if a comprehensive classification of these injuries were established.

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DISCUSSION

Dr. Robert Lee Patterson, Jr., New York, N. Y.: Dr. Pipkin has collected and recorded twenty-five cases of dislocation of the hip with fracture of either the head or neck of the femur. In studying his findings and those of several other authors on this subject, one is impressed with the following facts:

1. It is possible to get a well functioning hip after this severe injury if proper treatment is given, but the chances of doing so are small.

2. If follow-up is maintained sufficiently long, a high percentage of the hips will probably show avascular necrosis or degenerative joint disease.

3. A comparison of Dr. Pipkin's study with that of Henry and Bayumi in 1934 reveals that the only essential difference between these series is that whereas the mortality rate in the earlier series was 47 per cent, in Dr. Pipkin's series it was only 4 per cent.

I am sure that the successful results obtained in the treatment of types 1 and 2 in Dr. Pipkin's series were primarily due, as Dr. Pipkin stated, to prompt closed reduction and sufficient postoperative care. The shock suffered by these patients is great and often they have serious associated injuries which complicate the total picture. I certainly agree with Stewart and Milford that, regardless of the presence of other injuries, closed reduction should be attempted as soon as possible. If comminuted small fragments remain in the joint, they can be removed later. If closed reduction fails, the bone block or comminuted fragment can be excised, a weight-bearing hip being thus obtained. In the series reported by Henry and Bayumi in 1934, there was one surgical fracture of the femoral head and seventeen of the femoral neck during attempts at closed reduction. In Dr. Pipkin's series of twenty-five hips, there were two instances of surgical fracture. It should be said that the application of excessive force, the use of the ilium as a fulcrum, and prolonged manipulation (an hour or more) are contra-indicated. If an attempt to obtain reduction by the closed method fails, it is necessary to be sure that a fragment of bone is not blocking the reduction, making further attempts useless.

I would like to compliment Dr. Pipkin on getting together this series of Grade IV fracture-dislocations of the hip. Since degenerative changes can take place many years later, we hope that he will give us a further follow-up on these same cases. Only by this means can we know what happens and what to expect in such uncommon injuries.

Dr. Marcus J. Stewart, Memphis, Tennessee: Dr. Pipkin has presented a rather large series of cases. However, I feel that his findings become statistically unimportant when the cases are broken down into four types. I also feel that it is not wise, as a rule, to attempt to evaluate the final result in so severe an injury until after at least eighteen to twenty-four months of observation. In our series of 194 hips, fifty-six were discarded primarily because the follow-up period was less than twelve months. Among the remaining 128 patients, there were only seventeen who were not followed for over two years. In the cases in which avascular necrosis developed, the average time before onset was seventeen months after injury.

The author's emphasis upon the paramount features of treatment and rehabilitation is extremely important. As he again brought to our attention, there is no substitute for the early and accurate reduction of the femoral-head fracture if a good result is to be obtained. We have seen no case in which a good result was obtained when posterior dislocation, with or without a fracture, was left unreduced for more than twenty-four hours.

Col. Dehene and others have stressed the importance of a thorough initial examination of patients with multiple injuries in order not to overlook an associated fracture-dislocation of the hip. To paraphrase the old saying that for the loss of a nail, a shoe, a horse, a kingdom was lost, in this injury, for the loss of a day or even an hour, there may be the loss of a hip or even a life.

We agree that the Stimson method is the procedure of choice in the majority of dislocations. In the opinion of the late, beloved Dr. Albert Key, it is often not used because the surgeon is deprived of the satisfaction of the loud audible pop which is associated with other more traumatic methods of manipulation.

Fracture at the time of manipulation is more likely to occur if reduction is delayed. This situation is

(Continued on page 1197)

Replacement of the Femoral Head by Judet or Austin Moore Prosthesis*

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In spite of opinions varying from downright opposition to forthright enthusiasm, it seems that femoral-head prostheses are here to stay. As shown by the excellent study made by The American Academy of Orthopaedic Surgeons, prostheses of many types have been used by several hundred orthopaedists in several thousand cases. From this symposium varying conclusions have been drawn.

This report is limited to two types of femoral-head prostheses, the Judet and the Austin Moore. The purpose of this paper is to outline our experiences and to present statistical data which will aid in the evaluation of these prostheses as part of the orthopaedic surgeon's armamentarium. As experience was gained, a set of indications for and contra-indications to the use of these different types of prostheses was developed. An analysis of the results in relation to the pathological conditions found and the various aspects of treatment will be given.

MATERIAL

The material for study consists of 147 consecutive operations in which femoral-head replacement was done. The operations were performed by members of both the Resident and Attending Staffs of the New York Orthopaedic Hospital prior to March 1, 1955. In these patients seventy-five Judet (fifty-six acrylic and nineteen metallic) and seventy-two Austin Moore prostheses (Vitallium) were used.

As of March 1, 1956, we were able to study and to rate by means of the Judet method the results in 105 of the 147 patients with a follow-up period of not less than one year. Twenty-four of the remaining patients were studied but were not amenable to rating by the Judet method. In the follow-up study of the 105 patients it was found that there were fifty-five patients with Judet prostheses (forty-four acrylic and eleven metallic) and fifty patients with Austin Moore prostheses. We have divided the series into four groups according to the pathological condition: (1) acute fractures of the neck of the femur; (2) avascular necrosis of the femoral head; (3) non-union of the neck of the femur; and (4) osteo-arthritis of the hip joint. Of the 105 patients rated by means of the Judet method, seventy-five were followed from one to three years and thirty, from three to five years. The twenty-four remaining patients were followed for varying periods of time, frequently less than one year. Cases in which postoperative death occurred were excluded in the evaluation of the function. The length of follow-up ranged from four days (postoperative death) to five years (senile psychosis); in the majority of cases it was less than two years. Of the entire series, eighteen were lost to follow-up.

GRADING OF RESULTS

Rather than attempt to formulate a system of numerical grading, we have used the system published by the Judets. Tables II-A, II-B, III, IV-A, and IV-B show this method. The first column in Table II-A lists six grades of pain. The second column shows the total

* Read at the Annual Meeting of The American Orthopaedic Association, Banff, Alberta, Canada, June 23, 1956.

TABLE I

MATERIAL FOR STUDY

Pathological Condition	Type of Prosthesis		Number of Patients	Lost to Follow-up	Number of Patients Followed With Judet Rating	Without Judet Rating	Total
Acute fracture of neck of femur	Judet	Acrylic	15	3	5	7	12
		Metallic	8	1	4	3	7
		Total	23	4	9	10	19
	Austin Moore		24	1	14	9	23
		Total	47	5	23	19	42
Avascular necrosis of head of femur	Judet	Acrylic	12	1	11		11
		Metallic	4		4		4
		Total	16	1	15		15
	Austin Moore		1		1		1
		Total	17	1	16		16
Non-union of fractured neck of femur	Judet	Acrylic	7		7		7
		Metallic	2		1	1	2
		Total	9		8	1	9
	Austin Moore		20	2	15	4	19
		Total	29	2	23	5	28
Osteo-arthritis of hip	Judet	Acrylic	22	1	21		21
		Metallic	5	3	2		2
		Total	27	4	23		23
	Austin Moore		27	7	20		20
		Total	54	11	43		43
All groups	Judet	Acrylic	56	5	44	7	51
		Metallic	19	4	11	4	15
		Total	75	9	55	11	66
	Austin Moore		72	9	50	13	63
		Total	147	18	105	24	129

range of motion, and the third column shows the patient's ability to walk with or without support. After the results in a patient were graded, the three values determined were totaled; this sum represents the over-all result. This numerical grade is rated as *excellent*, *good*, *fair*, or *bad*, as shown in Table II-B. Examples of this calculation are given in Table III. Accordingly, a rating of *excellent* could be one in which there was no pain, a total range of motion between 140 and 200 degrees, and a normal gait. A rating of *fair* could be one in which there was pain with fatigue, a range of motion of 0 to 70 degrees, and the ability to walk short distances with one cane. We have modified the original Judet ratings in that we have set the requirements for all results somewhat higher than they were set by the Judets. The Judets set the standard at three points or less for a bad result, four to six points for a fair result, seven to nine points for a good result, and ten points or more for an excellent result. We felt that these figures did not give an entirely accurate

TABLE II-A

JUDET POINT SYSTEM FOR GRADING DISABILITY

Pain		Range of Motion		Ability to Walk	
Observation	Grade	Observation (*Degrees*)	Grade	Observation	Grade
Severe pain at rest	1	0 (limb in poor position)	1	Bedridden	1
Severe pain on walking	2	0 (limb in good position)	2	Walking very limited with or without a cane	2
Pain tolerable	3	0–70	3	Walking limited with one cane	3
Pain with fatigue	4	70–140	4	Long distances with one cane	4
Slight pain	5	140–200	5	No cane but limp	5
No pain	6	200–300	6	Normal	6

evaluation of the over-all clinical result and therefore raised the standards (Table II-B).

Grades given to a patient either before or after operation are absolute values. The difference between a preoperative and a postoperative grade is a relative value. These relative values are called amelioration rates and are measures of the amount of improvement or change resulting from treatment. Specifically, amelioration ratings are determined by subtracting the preoperative Judet rating from the postoperative Judet rating. The ratings for amelioration values have not definitely been set forth by the Judets, to the authors' knowledge. Therefore, we have set up a table of amelioration rating which we feel gives an accurate evaluation of the clinical improvement and which we believe is in keeping with the Judets' plan of evaluation.

These ratings are summarized in Table IV-A, and sample determinations are shown in Table IV-B. This grading system, in our estimation, is as good as any that has been published. However, one must recognize that it has deficiencies in that it does not take into account the motivation and cooperation of the patient or the status of the other hip.

RESULTS

The method of presenting the results used in the tables was chosen because it permits comparison between the pathological types and between the two prostheses (Tables V-A and V-B). Differences between percentages found may indicate trends and, unless otherwise stated, should not be considered significant statistically.

Acute Intracapsular Fractures of the Neck of the Femur

The criteria for using a prosthesis in the treatment of acute intracapsular fractures of the neck of the femur were: short life expectancy, technical impossibility of stable internal fixation, Pauwel's type III fracture in elderly patients, pathological fracture due to metastatic tumors, senility, parkinsonism, and hemiplegia.

Forty-two patients in whom femoral-head prostheses were inserted were followed in the acute-fracture group. In nineteen of the forty-two patients, the results could not be

TABLE II-B

JUDET TERMINOLOGY FOR RATINGS

Summation of Judet points *	Rating
8 or less	Bad
9–11	Fair
12–15	Good
16 or more	Excellent

* For pain, range of motion, and ability to walk.

TABLE III

SAMPLE CALCULATIONS USING JUDET SYSTEM

Patient	Observations	Judet Points	Judet Rating
L. C.	Pain	6	
	Range	5	
	Ability to walk	4	
	Total	15	Excellent
M. D.	Pain	2	
	Range	3	
	Ability to walk	1	
	Total	6	Bad

TABLE IV-A

TERMINOLOGY FOR AMELIORATION RATINGS

Total Gain in Judet Points *	Rating
2 or less	Bad
3–5	Fair
6–8	Good
9 or more	Excellent

* For pain, range of motion, and ability to walk.

Individual Gain in Judet Points *	Rating
1 or less	Bad
2	Fair
3	Good
4 or more	Excellent

* For pain, range of motion, or ability to walk.

TABLE IV-B

SAMPLE CALCULATIONS OF AMELIORATION RATES

Patient	Observation	Judet Points			Amelioration Rating
		Postoperative	Preoperative	Difference	
L. C.	Pain	6	1	5	
	Range	5	4	1	
	Ability to walk	4	5	−1	
	Total	15	10	5	Fair
M. D.	Pain	2	2	0	
	Range	3	3	0	
	Ability to walk	1	2	−1	
	Total	6	7	−1	Bad

evaluated by the Judet method for the following reasons: nine were unable to walk because of senility or cerebral vascular accident; three had complicating neurological disorders such as parkinsonism or residual hemiplegia from an old cerebral vascular accident; one had a persisting dislocation of the prosthesis; and six died postoperatively or during the period of convalescence.

TABLE V-A

RESULTS IN SERIES NOT EVALUATED BY JUDET SYSTEM

Pathological Condition	Type of Prosthesis		No. of Patients	Mean Age	Persistent Dislocation	Postoperative Deaths	Concurrent Crippling Disease	
Acute intracapsular fracture of neck of femur	Judet	Acrylic	7	81		2	Senility	2
		Metallic	3	77	1	2	Apoplexy	1
			—		—	—	Parkinsonism	1
		Total	10	80	1	4	Hypertensive cardiovascular	1
							Senility	4
							Carcinoma	2
	Austin Moore		9	75	0	2	Apoplexy	1
			—		—	—		—
		Total	19	78	1	6		12
Avascular necrosis of head of femur			None		None		None	
Non-union of fractured head of femur	Judet	Acrylic						
		Metallic	1	73	1			
			—		—			
		Total	1	73	1			
	Austin Moore		4	67		2	Senility	1
							Carcinoma	1
			—		—	—		—
		Total	5	68	1	2		2
Osteo-arthritis of the hip			None		None		None	
All groups		Acrylic	7	81		2	Senility	2
	Judet	Metallic	4	76	2	2	Apoplexy	1
							Parkinsonism	1
			—	—	—	—	Hypertensive	
		Total	11	79	2	4	cardiovascular	1
	Austin Moore		13	73		4	Senility	5
							Carcinoma	3
							Apoplexy	1
			—			—		—
	Grand Total		24	76	2	8		14

The mean age of the twenty-three patients with Judet evaluation was seventy-two years (Table V-B). The results in these patients show that two of the nine patients with Judet prostheses (five acrylic, four metallic) had good or excellent results. Both of these had an acrylic prosthesis. Of the fourteen patients in whom the Austin Moore prosthesis was used, eleven had good or excellent results.

It is in this group that the largest difference in the results between the two types of prosthesis was found; 22 per cent of the patients with the Judet prosthesis had good or excellent ratings and 79 per cent of the patients with the Austin Moore prosthesis had good or excellent ratings. This difference in percentages is statistically significant. (In this study statistical significance is based on the 0.95 level.) We have no ready explanation for this, except that the femoral neck usually undergoes osteoporosis and thus may give way under the Judet prosthesis, whereas the Austin Moore prosthesis has a better foundation on the thicker calcar femorale.

Avascular Necrosis in Healed Fractures of the Neck of the Femur

The criteria for using a prosthesis in this group of patients were: pain, roent-

TABLE V-B

RESULTS IN SERIES EVALUATED BY JUDET SYSTEM

Pathological Condition	Type of Prosthesis		No. of Patients	Mean Age	Judet Rating Good or Excellent		Fair or Bad	
Acute intracapsular fracture of neck of femur	Judet	Acrylic	5	70	2		3	
		Metallic	4	75			4	
		Total	9	72	2	(22%)	7	(78%)
	Austin Moore		14	71	11	(79%)	3	(21%)
		Total	23	72	13	(56%)	10	(44%)
Avascular necrosis of head of femur	Judet	Acrylic	11	62	10		1	
		Metallic	4	59	4			
		Total	15	62	14	(93%)	1	(7%)
	Austin Moore		1	49	1	(100%)		
		Total	16	62	15	(93%)	1	(7%)
Non-union of fractured head of femur	Judet	Acrylic	7	63	4		3	
		Metallic	1	70			1	
		Total	8	64	4	(50%)	4	(50%)
	Austin Moore		15	63	11	(73%)	4	(27%)
		Total	23	64	15	(65%)	8	(35%)
Osteo-arthritis of the hip	Judet	Acrylic	21	52	15		6	
		Metallic	2	53			2	
		Total	23	52	15	(65%)	8	(35%)
	Austin Moore		20	59	13	(65%)	7	(35%)
		Total	43	54	28	(65%)	15	(35%)
All groups	Judet	Acrylic	44	58	31	(70%)	13	(30%)
		Metallic	11	65	4	(36%)	7	(64%)
		Total	55	59	35	(64%)	20	(36%)
	Austin Moore		50	63	36	(72%)	14	(28%)
	Grand Total		105	61	71	(68%)	34	(32%)

genographic evidence of avascular necrosis, and beginning acetabular osteo-arthritis.

This group consisted of sixteen patients who were given Judet ratings. In fifteen of the sixteen patients Judet prostheses were used. There were fourteen good or excellent results among the patients with Judet prostheses (ten acrylic and four metallic). The one patient with the Austin Moore prosthesis had a good result. This, of course, is not a basis for comparison. The age of these patients averaged sixty-two years, and the average period from the time of fracture to the time of operation was three years.

Our experience with the Judet prosthesis was excellent in this group with avascular necrosis. However, there is no comparable series in which the Austin Moore prosthesis

TABLE VI

NUMBER OF PATIENTS WITH GOOD OR EXCELLENT AMELIORATION RATES IN SERIES EVALUATED BY JUDET SYSTEM

Pathological Condition	Type of Prosthesis		No. of Patients	Patients With Good or Excellent Amelioration Rates: Individual Ratings: Pain	Motion	Walking	Over-all Ratings
Acute intercapsular fracture of neck of femur				Amelioration rate not applicable			
Avascular necrosis of head of femur	Judet	Acrylic	11	2	0	3	3
		Metallic	4	2	0	2	2
		Total	15	4 (27%)	0	5 (33%)	5 (33%)
	Austin Moore		1	1 (100%)	0		1 (100%)
		Total	16	5 (31%)	0	5 (31%)	6 (38%)
Non-union of fractured head of femur	Judet	Acrylic	7	4	0	1	3
		Metallic	1	0	0	0	0
		Total	8	4 (50%)	0	1 (13%)	3 (37%)
	Austin Moore		15	7 (46%)	0	6 (40%)	5 (33%)
		Total	23	11 (48%)	0	7 (30%)	8 (35%)
Osteo-arthritis of the hip	Judet	Acrylic	21	15	2	2	8
		Metallic	2	0	0	0	0
		Total	23	15 (65%)	2 (8%)	2 (8%)	8 (34%)
	Austin Moore		20	9 (45%)	2 (10%)	5 (25%)	10 (50%)
		Total	43	24 (56%)	4 (9%)	7 (16%)	17 (38%)
All groups	Judet	Acrylic	39	21 (54%)	2 (5%)	6 (15%)	14 (36%)
		Metallic	7	2 (29%)		2 (29%)	2 (29%)
		Total	46	23 (50%)	2 (4%)	8 (17%)	16 (35%)
	Austin Moore		36	17 (47%)	2 (6%)	11 (30%)	16 (44%)
	Grand Total		82	40 (49%)	4 (5%)	19 (23%)	32 (39%)

was used. A possible explanation for the good results found in patients with the Judet prosthesis may be the fact that, in cases of avascular necrosis, the neck of the femur is more sclerotic than it is in fresh fractures and thus provides a firmer foundation on which to rest the Judet prosthesis. It should be noted that surgery was performed upon these patients before the onset of severe osteo-arthritic changes in the acetabulum.

Non-union of Fractures of the Neck of the Femur

The criteria for surgical replacement of the upper end of the femur in patients with non-union were pain and instability. There were twenty-eight patients in this group. The results in five patients could not be evaluated by the Judet system. Two of these five patients died postoperatively, one from pneumonia and one from miliary tuberculosis; two were too debilitated or uncooperative because of carcinoma and senility, respectively; and one had a persisting dislocation of the prosthesis. The average age of these patients

TABLE VII

NUMBER OF PATIENTS USING VARIOUS TYPES OF POSTOPERATIVE SUPPORT IN SERIES EVALUATED BY JUDET SYSTEM

Pathological Condition	Type of Prosthesis	No. of Patients	Type of Support: None	One Cane	Two Canes	One Crutch	Two Crutches	Walker	Wheelchair
Acute intracapsular fracture of neck of femur	Judet Acrylic	5	2	1		1		1	
	Judet Metallic	4		1	1	1	1		
	Judet Total	9	2	2	1	2	1	1	
	Austin Moore	14	3	9	1	1			
	Total	23	5	11	2	3	1	1	
Avascular necrosis of head of femur	Judet Acrylic	11	6	4		1			
	Judet Metallic	4	1	2					1
	Judet Total	15	7	6		1			1
	Austin Moore	1		1					
	Total	16	7	7		1			1
Non-union of fractured head of femur	Judet Acrylic	7	2	3	1	1			
	Judet Metallic	1					1		
	Judet Total	8	2	3	1	1	1		
	Austin Moore	15	3	7			5		
	Total	23	5	10	1	1	6		
Osteo-arthritis of the hip	Judet Acrylic	21	8	7	2	1	3		
	Judet Metallic	2	1	1					
	Judet Total	23	9	8	2	1	3		
	Austin Moore	20	4	8		5	3		
	Total	43	13	16	2	6	6		
All groups	Judet Acrylic	44	18 (41%)	15 (34%)	3 (7%)	4 (9%)	3 (7%)	1 (2%)	
	Judet Metallic	11	2 (18%)	4 (36%)	1 (9%)	1 (9%)	2 (18%)		1 (9%)
	Judet Total	55	20 (36%)	19 (35%)	4 (7%)	5 (9%)	5 (9%)	1 (2%)	1 (2%)
	Austin Moore	50	10 (20%)	25 (50%)	1 (2%)	6 (12%)	8 (16%)		
	Grand Total	105	30 (29%)	44 (42%)	5 (5%)	11 (10%)	13 (12%)	1 (1%)	1 (1%)

was sixty-eight years. The average period from the time of the original fracture to the date of surgery was twenty months.

There were twenty-three patients with non-union for whom it was possible to make an evaluation of results according to the Judet method (Table V-B). In eight of these patients replacement was done with the Judet prosthesis (seven acrylic, one metallic), and four had good or excellent results. In the remaining fifteen patients, the Austin Moore prosthesis was used, and eleven had good or excellent results. The average age of the twenty-three patients was sixty-four years, and the elapsed time from the original fracture to the time of operation averaged two years.

TABLE VIII

RESULTS (JUDET RATINGS) CORRELATED WITH CAPSULECTOMY (PARTIAL OR COMPLETE)

Group		With Capsulectomy	Without Capsulectomy
Acute fracture of neck of femur (23 cases)	Total number of cases	3	20
	Cases rated good or excellent	2 (67%)	11 (55%)
	Cases rated fair or bad	1 (33%)	9 (45%)
Avascular necrosis of head of femur (16 cases)	Total number of cases	6	10
	Cases rated good or excellent	5 (83%)	10 (100%)
	Cases rated bad or fair	1 (17%)	0
Non-union of neck of femur (21 cases) *	Total number of cases	12	9
	Cases rated good or excellent	10 (83%)	4 (44%)
	Cases rated bad or fair	2 (17%)	5 (56%)
Osteo-arthritis of the hip joint (40 cases) **	Total number of cases	25	15
	Cases rated good or excellent	17 (68%)	9 (60%)
	Cases rated bad or fair	8 (32%)	6 (40%)
All groups (100 cases)	Total number of cases	46	54
	Cases rated good or excellent	34 (74%)	34 (61%)
	Cases rated bad or fair	12 (26%)	20 (39%)

* Two cases of original twenty-three fracture cases excluded because of lack of sufficient information.
** Three cases of original forty-three osteo-arthritis cases excluded because of lack of sufficient information.

Analysis of the results found in this group of patients with non-union indicates that the patients in whom the Austin Moore prosthesis was used had better results than those in whom the Judet prosthesis was used. However, this difference in results is not statistically significant.

Osteo-arthritis of the Hip

The chief indication for surgery in the group with osteo-arthritis was pain. Of secondary importance was limitation of motion. There were forty-three patients in this group, for all of whom the Judet evaluation system could be used. Fifteen of the twenty-three patients in whom the Judet prosthesis was used (twenty-one acrylic and two metallic) and thirteen of the twenty patients in whom the Austin Moore prosthesis was used had good or excellent results (Table V-B). These patients averaged fifty-four years of age. Most had had pain for about ten years; the duration of symptoms ranged from one year to thirty-nine years.

Analysis of the two groups shows that there was no difference in the percentage of good or excellent results.

When all factors were considered, it was found that seventy-one (67 per cent) of the 105 patients with Judet ratings had good or excellent results. Of the twenty-four other patients followed, sixteen had concurrent complications and eight died post-operatively or in the period of convalescence (Table V-A).

AMELIORATION RATES

Since fresh fractures do not lend themselves to the study of amelioration, such rates cannot be reported for the patients with acute fracture of the neck of the femur.

The last column in Table VI shows that the amelioration rate in each group (aseptic necrosis, non-union, and osteo-arthritis) was about the same. In slightly more than one-third of the patients in each group, the rate was good or excellent. A breakdown of individual amelioration rates on the basis of pain, range of motion, and ability to walk is

TABLE IX

RESULTS (JUDET RATINGS) CORRELATED WITH REAMING OF THE ACETABULUM

Group		Reamed	Not Reamed
Non-union of neck of femur (23 cases)	Number of cases	4	19
	Cases rated good or excellent	2 (50%)	6 (32%)
	Cases rated bad or fair	2 (50%)	13 (68%)
Osteo-arthritis of the hip joint (43 cases)	Number of cases	29	14
	Cases rated good or excellent	9 (31%)	7 (50%)
	Cases rated bad or fair	20 (69%)	7 (50%)

also given in Table VI. No definite trends were noted. In general, however, the greatest degree of improvement usually occurred in the reduction of pain, the next greatest in the ability to walk, and the least in the range of motion.

To show the results in another manner, we have tabulated the series of 105 cases on the basis of need for support (Table VII). Seventy-four patients (71 per cent) were using either no support or one cane.

OPERATIVE TECHNIQUE

Incision

In the entire series of 129 patients for whom follow-up data were obtainable, the Smith-Petersen incision was used in eighty-six patients, the Watson-Jones incision in twenty-eight, and the Gibson incision in fifteen. In patients with acute fractures, a Smith-Petersen incision was used when the decision to replace the upper end of the femur was made prior to surgery. When such a decision was to be delayed until after the hip was exposed, a Watson-Jones incision was used in order to achieve simultaneous exposure of the femoral head and the greater trochanter in the event nailing was feasible.

In the patients with avascular necrosis and with non-union, the Smith-Petersen incision was preferred because it does not disturb the greater trochanter and because very few patients require reaming of the acetabulum. An effort to correlate the type of incision with the rapidity of convalescence showed no significant difference among the three incisions used.

In the group with osteo-arthritis thirty-five patients had the Smith-Petersen incision and eight had the Gibson incision. The advantage of the Gibson incision is one of technique. It affords better exposure for reaming the acetabulum or for transplantation of the greater trochanter, if either is indicated.

It might be added here that in patients in whom there had been loss of effective length of the femoral neck, distal transplantation of the greater trochanter is believed to have improved the result. This transplantation restores functional length of the hip abductors, resulting in less limp.

Capsulectomy

In 100 of the patient for whom Judet ratings were made the operator noted in his report whether or not a capsulectomy was performed. In forty-six of the 100, capsulectomy was done in order to permit a greater range of motion and to denervate the joint. An analysis of the results shows that capsulectomy produced little or no difference in the percentage of over-all good results, except in the patients with non-union in whom it produced a considerably higher percentage of good or excellent results. In general, however, excellent results could be found in both groups in all categories. This finding surprised us as it had previously been assumed that capsulectomy was an essential part of the procedure especially in patients with osteo-arthritis (Table VIII).

FIG. 1

FIG. 2-A

Fig. 1: Stem of Austin Moore prosthesis was forced through cortex of the femur at insertion.

Figs. 2-A through 2-C: Infection occurred in this patient and the prosthesis was removed. Fig. 2-A shows the preoperative condition. After removal of the prosthesis (Fig. 2-C) the patient walked with the aid of one cane and had little pain.

FIG. 2-B

FIG. 2-C

FIG. 3-A

FIG. 3-B

Fig. 3-A: Roentgenogram made immediately after the insertion of acrylic Judet prosthesis after fracture.
Fig. 3-B: Four years after operation, the patient used one crutch and had pain.

Reaming

Reaming of the acetabulum (Table IX) was performed in twenty-nine of the forty-three patients with osteo-arthritis but was rarely performed in the other groups. In the group of osteo-arthritic patients with Judet evaluation, seven of the fourteen patients upon whom reaming was not done showed an amelioration rate of good or excellent, whereas only nine of the twenty-nine patients in whom reaming was done fell into this category. One may interpret these figures as indicating that reaming of the acetabulum may not be an essential part of the procedure and that it is not to be recommended unless the acetabulum needs to be deepened or altered to provide congruity of moving surfaces. It should be noted, however, that in general the hips with more severe osteo-arthritic changes were reamed and that those with less severe changes were not reamed. It was the practice to ream the acetabulum until it was smooth in those patients with extensive osteo-arthritis. It is believed that when reaming is done, normal hyaline cartilage is never reconstituted in the acetabulum and thus one cannot expect as good a result as that obtained in the patient in whom there is normal acetabular cartilage which requires no reaming. In four of the twenty-three patients with non-union the acetabulum was reamed. Of these two had a good or excellent amelioration rate. Of the nineteen in whom the acetabulum was not reamed, six (32 per cent) had a good or excellent rating. There was only one patient in the group with avascular necrosis in whom the acetabulum was reamed and there were none in the fracture group. The amelioration rate in the patient with avascular necrosis was good.

Immobilization

Patients with acute fractures were permitted to walk as early as possible and to bear weight. Twenty-one of the twenty-three patients walked within forty-eight hours. In the other groups the type of immobilization was determined on the basis of the patho-

FIG. 4-A

FIG. 4-B

The Judet prosthesis, which had loosened and settled, was replaced with an Austin Moore prosthesis. The result was good.

logical condition, type of incision, extent of capsulectomy, and whether or not the acetabulum had been reamed.

The majority of patients having surgery for osteo-arthritis of the hip were placed in plaster spicas at the time of surgery. Those patients who required extensive dissection and in whom the stability of the prosthesis in the acetabulum was poor, were kept in the spica for two to three weeks. We felt that the patients upon whom extensive dissections had not been done and in whom there was no danger of dislocation should nevertheless be placed in spicas for seven to ten days for comfort, ease of nursing care, and sound wound healing. Older patients who cannot tolerate spica immobilization are exceptions. It was felt that patients made more rapid progress in regard to range of motion after this period of immobilization than they would have made if they had exercised from the beginning.

Time in Hospital

The average length of time spent in the hospital by patients with acute fractures was four and one-half weeks; by patients with aseptic necrosis, four weeks; by patients with non-union, six weeks; and by patients with osteo-arthritis, seven weeks. It is apparent that length of hospitalization is related to the extent of surgery.

Early Complications

The immediate complications encountered in the original series of 147 patients were as follows. There were five dislocations of the prosthesis; three of the prostheses were the Judet type (two acrylic, one metallic) and two were the Austin Moore. In three patients a fracture of the upper end of the femur occurred at the time of the insertion of an Austin Moore prosthesis. These fractures occurred early in this series in patients upon whom more force was used in seating the prosthesis than was used in subsequent patients. At

FIG. 5-A

FIG. 5-B

Roentgenograms show the metallic Judet prosthesis in use at present, one month after insertion for fracture (Fig. 5-A) and nine months later (Fig. 5-B). Note absorption of the femoral neck.

present a V-shaped notch is made in the greater trochanter before introduction of the Austin Moore prosthesis. The stems of two Austin Moore prostheses protruded laterally through the shaft of the femur, also early in the series.

Figure 1 shows the stem of an Austin Moore prosthesis protruding laterally through the shaft of the femur. In the procedures used at the present a roentgenogram is made with a portable x-ray unit in the operating room in order to check the position of the stem prior to final seating.

The wounds in two patients became grossly infected so that removal of the prosthesis was required. In these two patients neither dislocation nor infection spelled total disaster. Both are using two canes and are able to walk about a half mile with little pain (Figs. 2-A, 2-B, and 2-C). Six patients with acute fractures whose average age was nearly eighty died soon after operation. One fatal cardiac arrest occurred. In five patients there were non-fatal pulmonary emboli.

Late Complications

Gross loosening of the stem of the prosthesis in the neck of the femur occurred in eight of the patients with the Judet prosthesis (five acrylic, three metallic). Loosening of the stem became apparent in these patients at periods ranging from two to thirty-six months. Pain occurred and loosening of the prosthesis was discovered an average of fifteen months after operation. Replacement with the Austin Moore prosthesis was indicated because of pain and sense of instability. In four of these patients a fracture of the acrylic stem or rim was found. This complication can be avoided by the use of the metallic Judet prosthesis. Results more than one year after revision in four of these patients were available for study. Two results were good, one was fair, and one was bad. In one patient a dislocated acrylic prosthesis was replaced by a metallic Judet prosthesis, which also

subsequently dislocated. In three other patients in whom a Judet prosthesis was used, operative revision was required. In two of these there was settling of the prosthesis which made the tip of the stem too prominent in the trochanteric region. In another patient capsulectomy was required to remove an excessive deposit of bone.

It should be noted that there was a 17 per cent rate of revision or replacement in patients in whom the Judet prosthesis was used in this series (seven acrylic, four metallic).

DISCUSSION

The data presented here raise a number of questions. How do the results of using these hip prostheses compare with the results from other forms of hip-joint reconstruction? Is the use of these prostheses justifiable?

It is worthwhile to consider the four groups separately. In patients with acute fractures treated early in this series the decision to use a prosthesis was based not only on the general experience with prostheses but also on the incidence of failure with nailing and other forms of treatment. The incidence of failure resulting from other forms of treatment is a highly controversial subject. If the high estimates of failure are accurate, that is, if the incidence of failure in patients with non-union or avascular necrosis is 75 per cent, there seems to be little doubt that there is a definite place for the femoral-head prosthesis, especially in a group of patients who meet our criteria for replacement.

The clearest indication for replacement of the femoral head seems to be the presence of avascular necrosis. With death of all or part of the femoral head, little reliance can be placed on continued support of a Smith-Petersen mold nor can one expect to attain hip fusion with any degree of certainty.

The results in the patients with non-union of a fractured femoral neck serve only to strengthen the general conviction that repair of such non-union by osteotomy and bone-grafting should be performed if the procedure is technically feasible and if the femoral head is viable.

In the treatment of osteo-arthritis of the hip, the results appear to be comparable to those obtained with Smith-Petersen molds and femoral osteotomies. Consequently, the decision to use a prosthesis should depend chiefly upon the bony anatomy of the hip joint *per se* and the experience of the surgeon. The advantage, if any, that prostheses have over the other forms of reconstruction of the hip is the fact that the postoperative period of immobilization is not nearly as long. We continue to prefer to fuse the hip in the treatment of unilateral hip-joint osteo-arthritis, provided the patient is able to withstand the prolonged spica immobilization; otherwise an intramedullary prosthesis is preferred.

When the decision to use a prosthesis has been made, there still is a choice between the Austin Moore and the Judet types. There is no doubt that the Judet prosthesis should not be used if there is insufficient length of the femoral neck. But what of the patients upon whom a technically satisfactory Judet replacement could be performed? Shall we recommend that in these the neck be resected and an Austin Moore prosthesis be inserted? The data indicate that in acute fractures the rate of failure with the Judet prosthesis is sufficiently great so that the Austin Moore can be considered the prosthesis of choice. Concerning the patients with avascular necrosis we have little data for comparison. Our experience with the Judet prosthesis is quite good. In the group with non-union, the Austin Moore prosthesis appears to yield better results and may constitute the prosthesis of choice. However, the two series in this group are so small that the difference in the results may be attributable to chance. In most of these patients with non-union, replacement of the femoral head cannot be performed satisfactorily with a Judet prosthesis because of absorption of the femoral neck.

In patients with osteo-arthritis the choice is more difficult. The results are not significantly different. The Judet prosthesis has perhaps a slight superiority over the Austin Moore prosthesis in the relief of pain. It would appear, nevertheless, that the use of the

Austin Moore prosthesis carries with it less of a risk in regard to long-term results. We have seen Judet prostheses that have become loose to such a severe degree that re-operation was required (Figs. 3-A and 3-B). In addition, there were a number of patients with Judet prostheses who reported beginning pain and whose hips have shown roentgenographic evidence of bone deterioration. These hips may eventually require re-operation. In this series, none of the Austin Moore prostheses have loosened or shown deterioration. On the contrary, we have noted a steady improvement in many of the patients after operation. It would seem, then, that in the treatment of osteo-arthritis the Austin Moore prosthesis is slightly preferable to the Judet. In this series, whenever a Judet prosthesis required replacement due to loosening or structural failure, an Austin Moore prosthesis was substituted.

Metallic Judet prostheses have completely replaced the acrylic type because of the numerous instances of failure that have been encountered with the acrylic material. However, we have also noted loosening of the metallic Judet prosthesis which is attributed to inadequacy of design.

Another problem which may arise is the possibility of further surgery when a prosthesis or its revision has failed. Perhaps the best recourse is the removal of the prosthesis (Figs. 2-A, 2-B, and 2-C). This allows the patient to walk or to bear weight against the fibrous tissue lateral to the acetabulum. The three patients in whom such a procedure was necessary are walking much better than had been expected. Arthrodesis of the hip may also be done in selected instances.

In conclusion, it may be said that an over-all appraisal shows that the results were mediocre. At the same time it must be pointed out that in many patients the femoral-head prostheses have been used with results that were gratifying to both the patient and the surgeon.

Prostheses do not constitute a panacea for the relief of hip-joint affections. Research must continue directed toward a better solution.

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A Femoral Intramedullary Nail

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The use of intramedullary nailing was first reported in 1907 by Lambotte. Schöne described his experiences with this method in 1913, and similar reports were made by Joly and Danies in 1935 and 1937, respectively.

In a report made in 1939, Küntscher described elaborations of the method and stated that there are more indications for its use—in fractures of the short bones as well as in those of the long bones—than had been formerly thought. As a result of Küntscher's work, intramedullary nailing will undoubtedly retain its present important place in the treatment of fractures for many years.

Despite the excellence of Küntscher's work, however, it has been found that the nail he designed does not meet all requirements. One of its principal shortcomings is that even when inserted into the medullary canal with considerable force, it sooner or later becomes loose. When this occurs in the femur, the nail migrates proximally, sometimes moving so far that its proximal end strikes against the wing of the ilium or comes to rest over the iliac crest where it can be palpated under the skin. This migration of the nail is probably caused by slight movements along the line of the fracture and may occur even if the limb is completely immobilized in a plaster cast. Some surgeons erroneously believe that the nail becomes loose in the medullary canal as a result of the growth of intramedullary callus about the lower end of the nail. This explanation is disproved by the fact that the nail often migrates very soon after the operation, before formation of intramedullary callus could possibly occur. It is obvious that a nail which has been inadequately inserted can become loose more easily than one which has been properly inserted.

Even a Küntscher nail which has been inserted properly, that is, with a force which is almost sufficient to break the bone, may become loose, for every bone responds to some degree to constant pressure.

All who have used Küntscher nails know that there is not quite a sufficient selection of sizes. Sometimes the smallest size may be easily inserted, while at other times it is too thick. Sometimes the medullary canal is so large that a single nail cannot provide adequate fixation and it is necessary to use two nails fitted together.

The possibility of rotation of the fragments, especially in fractures of the femur, is another drawback of the Küntscher nail. Rotation of the nail itself occurs most easily in the proximal fragment of the femur, the medullary canal of this portion being broad and the bone of the greater trochanter being comparatively soft. It can be objected, however, that the Küntscher nail will be held firmly without rotation if it is adequately inserted into the compact bone.

If the Küntscher nail is used following resection of the femur in order to shorten the limb or to remove a tumor, there is a possibility of distraction of the resected ends if they are not firmly secured. Hence, there is also the possibility of rotation of the upper fragment and even of the lower fragment.

The other complications which may occur in the use of the Küntscher nail, such as bending or breaking of the nail, are common in all similar methods of intramedullary nailing.

To meet the disadvantages of the Küntscher nail modified nails have been designed. In the English-speaking countries the nail designed by Hansen and Street [3] (the diamond-shaped medullary nail) is most commonly used. If a Hansen-Street nail of the correct dimensions is selected, the fragments cannot move. Following resection of the femur,

however, this nail may become loose or the fragments may be distracted. The Rush nail is also commonly used in the English-speaking countries.

In the Soviet Union Dubrov designed a solid round nail with an enlarged flat head. When this nail is used, the upper fragment cannot move, but rotation of the lower fragment may occur; also the nail may migrate proximally or, following resection of the femur, the fragments may be distracted.

In Germany, Maatz fitted together two or more grooved Küntscher nails, between the lower ends of which wedges had been inserted. This device was inserted so that the lower ends of the nails impinged against the walls of the medullary canal. Maatz also designed a nail with a conical enlargement of the proximal end. This nail is inserted into the greater trochanter of the femur and results in better fixation not only of the trochanter but of the intertrochanteric region as well.

In the various nails described above some of the faults of the Küntscher nail have been eliminated. Other faults have not been corrected, however, with the result that migration of the nail, rotation of the fragments, and distraction of the fragments are still possible complications. Furthermore, selection of a nail of suitable dimensions is still a difficult problem which is made more complicated by the fact that the size of a single medullary canal varies, so that a nail which will fit one section will not fit another.

Because of the drawbacks of the nails described above, the author has attempted to design a nail which can be inserted into the medullary canal with precision and accuracy and which will obtain firm immobilization of the fragments. Special instruments for preparing the medullary canal have also been designed.

The author's nail has been used in thirteen patients in whom resection of the femur was done in order to shorten the lower limb. These operations were performed between November 1954 and June 1956. The length of bone resected varied from four centimeters to nine centimeters. This nail has also been used in a patient (Case 13) with a pathological fracture.

The resection was done by means of instruments especially designed to obtain precise fashioning of the cut surfaces. In two cases the ends of the fragments were cut transversely; in the remaining cases they were cut conically in order to provide a larger area for the formation of endosteal callus. Apposition of surfaces cut in this fashion can be obtained with such precision that firm immobilization is automatically secured following insertion of the nail, making any external immobilization unnecessary and enabling the patient to begin exercises and careful weight-bearing as soon as the postoperative pain has disappeared, a week or two after the operation. In the first case in which we used this nail, the patient got out of bed the second day after the operation and walked, without crutches, into the next room for a smoke—despite the fact that his right limb had been shortened eight centimeters! On the average, the patient began to walk with almost complete weight-bearing the first or at least the second week after the operation; only a very few patients did not begin weight-bearing until the third week.

DESCRIPTION OF THE NAIL

The nail is made of stainless steel (Poldi anticorro AKVS), which is very tough and which has so far proved satisfactory. If for any reason stainless steel becomes unavailable or ceases to be satisfactory, we shall probably substitute Vitallium or some similar alloy.

The nail consists of two parts, the outer nail (Fig. 1, *a*) and the central spreader nail (Fig. 1, *b*). The outer nail is a tube with an enlarged hollow cylindrical head. This head is longitudinally grooved and has screw threads on its inner surface. On its upper end there are two flat surfaces designed to make it possible to tighten the nail by means of a thirteen-millimeter wrench. The lower end of the head is sharply bevelled to meet the shaft of the nail, which is smooth. The lower end of the shaft is divided into two opening jaws. These jaws have oval ends which have been milled from the outside and which, at the tips, are

FIG. 1

Fig. 1: *a*. The outer nail. The head is longitudinally grooved and is joined to the shaft by sharply beveled sides. There are two flat surfaces on the upper portion. The nail terminates in two opening jaws, the ends of which are deeply grooved. The interior of the nail, except at the tips of the jaws, is hollow, and there are threads on the inner surface of the head. *b*. The central expansive nail. The head of the inner nail is square. The rod of the nail is solid and has threads on its upper portion, which is enlarged. The end is shaped like a cone. *c* and *d*. Outer nails with central nails inserted. Note the length of the jaws.

FIG. 2-A

FIG. 2-B

Fig. 2-A: A femoral specimen showing the nailing device inserted. The central nail has been screwed in. The outer nail has short jaws.

Fig. 2-B: In this specimen a nail with long jaws has been inserted.

solid. At the upper end of the notch between the jaws there is a round hole designed to prevent splitting of the tube.

The central nail consists of a solid rod with an enlarged, threaded upper portion and a square head. The tip of the shaft is cone-shaped with sides which slope at an angle of 9 degrees. The diameter of the main portion of the shaft is one millimeter less than the diameter of the shaft of the outer nail; this makes it possible to insert or withdraw the central nail even if the outer nail is slightly bent. In Figure 1, *c* and *d*, the central nail is shown inserted into the outer nail as far as possible. The extent of the opening of the jaws is determined by how far the inner nail extends within the shaft of the outer nail; this, of course, is primarily determined by the length of the inner nail and for this reason each outer nail should be matched by a selection of inner nails of two to four different lengths. The extent of the opening of the jaws is also determined by the length of the jaws themselves; Figure 1, *d* shows the longer jaws with a larger opening. The longer jaws have a weaker opening power.

The purpose of the nail is to provide such reliable immobilization of the fragments that they will be able to withstand the pressure of rotation, extension, distraction, or any other dislocating force. To do this the nail must remain firmly in place, that is, it must not migrate or, as we say, walk out.

The head of the nail is elongated in order that the full length of the shaft may be inserted into the femur. A portion of the head of the nail should extrude above the greater trochanter. This portion should not exceed more than one-half the length of the head (Fig. 2-A) and preferably should be only a quarter (Fig. 2-B). In order to prevent rotation of the nail within the spongiosa of the greater trochanter, the head is roughly grooved. It is a great mistake to insert the full length of the head into the trochanter, for if this is done, the nail has no grip. The opening for the nail head can be prepared by means of a reamer (Fig. 3, *c*) which has a diameter two millimeters smaller than the diameter of the head.

It is necessary to realize that the jaws may not open evenly or symmetrically. If the jaws extend as far as the lower half of the femur, where the medullary canal is irregularly enlarged, one of the jaws may be pressed against the walls of the canal before the central nail has even been inserted and therefore before the jaws have been opened. In this case the second jaw will open further than the first, causing a curvature of the lower end of the nail. This does not prevent solid fixation of the nail and immobilization of the fragments, however (Figs. 5-B, 6-A, and 6-B), nor does it hinder removal of the nail, as has been demonstrated in Cases 1, 2, 3, and 4. In order that the full length of the nail may be easily inserted, the medullary canal should be prepared by means of two reamers, the conical reamer shown in Figure 3, *a* and the conventional reamer shown in Figure 3, *b*. The diameter of these reamers is 0.1 millimeter larger than the external diameter of the outer nail, a difference which is sufficient to ensure easy insertion of the nail.

The function of the lower end of the nail is to prevent rotatory or longitudinal movements which will result in distraction of the lower fragment and to prevent migration of the nail in a proximal direction. In order to make possible the attainment of these functions, sharp notches are made on the surfaces of the jaws.

The opening power of the jaws, especially of the shorter jaws, is great and equals pressures of 400 to 500 kilograms. For this reason the device must be inserted carefully (although firmly); also particular care must be taken in opening the longer jaws, since they may break at their base. The indications for use of the nail with long jaws are still limited.

If all these technical requirements are met, the device will maintain firm immobilization of the fragments not only when subjected to the pressure of the weight of the whole limb during rehabilitation exercises but also when subjected to the pressure of the weight of the entire body during weight-bearing without crutches. And, most important, the device can withstand these pressures almost immediately after the operation and can continue to withstand them almost indefinitely. This functional strength of the device is the result of its firmness, for the solid central nail reinforces the tubular outer nail. The device ceases to be of functional value after the fragments have been united by periosteal and endosteal callus, which usually takes place within six to twelve months.

The dimensions of the device, and especially of the opening jaws, must be carefully selected with the type of fracture and the dimensions of the medullary canal in mind. If it is not necessary for the device to extend beyond the middle portion of the femur, that is, if it is not to reach the enlarged portion of the medullary canal, a nail with shorter jaws should be used. If, however, it is necessary for the device to extend into the lower third of the femur, where the medullary canal is enlarged, a nail with longer jaws should be used. If a nail with longer jaws is not inserted sufficiently far so that the jaws reach the enlarged portion of the canal, the jaws may not be able to open and eventually may even be forced together (Figs. 9-A and 9-B). The fact that the longer jaws have a weaker

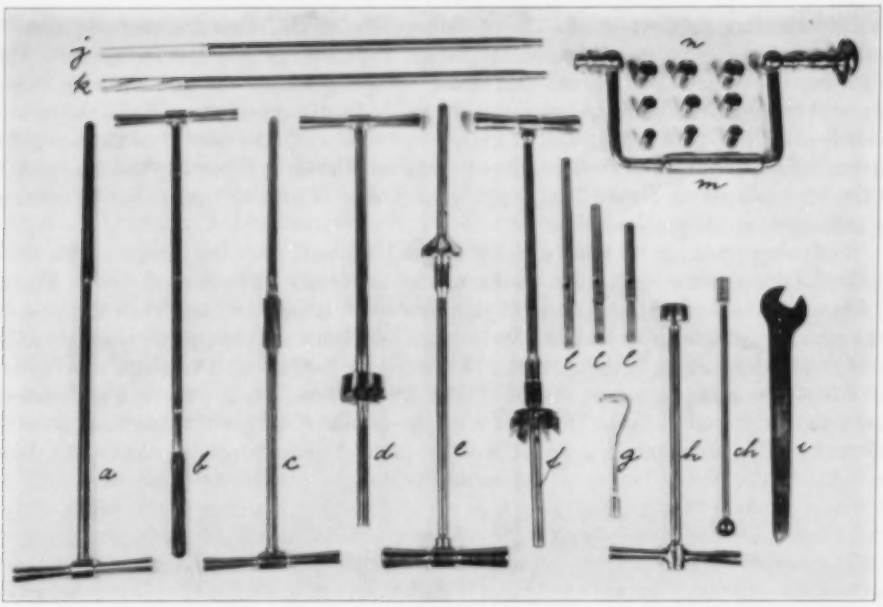

FIG. 3

a. Conical reamer. *b*. Straight reamer. *c*. Excavating reamer with a lead pole. *d*. Leveling cutter with a lead pole. *e*. Angle cutter with an external conical part and a lead pole. *f*. Angle cutter with an inner conical part and a lead pole. *g*. Hook for removing the nail by Küntscher's technique. *h*. Manual wrench with a square head for insertion of the inner nail. *ch*. Pole with a ball for knocking out the nail. *i*. Wrench for inserting the thirteen-millimeter nail head. *j*. Conical reamer to be attached to the brace. *k*. Straight reamer to be attached to the brace. *l*. Lead poles of various lengths to be attached to the cutters shown in *d*, *e*, and *f*. *m*. Brace. *n*. Adapters which, when placed on the lead poles of the cutters, act as guides to keep the cutters centered in the medullary canal. Note: The hook (*g*) may be used as an extractor by attaching it to the ball of the pole (*ch*), the other end of which is screwed into the nail.

opening power is, of course, a factor in this situation. It would seem that nails with long jaws are especially indicated for spiral fractures of the lower half of the femur, for in these fractures the jaws are not subjected to such great strains as they are in other types of fracture.

OPERATIVE TECHNIQUE

This nail has been used in thirteen patients operated upon to shorten the femur and in one patient with a pathological fracture. The technique of the operation used is as follows. An incision is extended from the level of the greater trochanter halfway down the thigh. Following separation of the periosteum about the upper portion of the femur, the section of bone to be removed is marked. Further marks are made so that rotation of the fragments may be avoided at the time of final fixation. The indicated section is then removed by means of a Gigli or electrical reciprocating saw or by means of an osteotome (the electrical circular saw is not suitable for this type of resection). The upper cut is made two to three centimeters below the lesser trochanter. Following the resection, the medullary canal must be enlarged so that its diameter is 0.1 millimeter greater than the diameter of the outer nail. First a conical reamer is inserted in a retrograde fashion into the upper fragment through the spongiosa of the greater trochanter as far as the trochanteric fossa. Another reamer is then used to widen the canal to the correct dimensions. The opening for the head of the nail is drilled by still other reamers. The diameter of this opening must be about two millimeters smaller than the diameter of the head in order that the grooved head will be firmly held by the bone of the greater trochanter. One-half or, preferably, three-quarters of the head should be implanted within the bone, the remaining

portion extruding above the bone. The medullary canal of the lower fragment is prepared by means of the same reamers used to prepare the canal of the upper fragment. The canal in this fragment is curved and must be straightened, the straightening being extended in the direction of the knee joint for ten to twelve centimeters. If the medullary canal is so narrow that a great deal of energy and time would be needed to prepare it by the regular reamers, a device consisting of the reamers shown in Figure 3, *j* and *k*, attached to the brace shown in Figure 3, *m*, may be used. Use of an electrical motor to operate these reamers seems problematical.

Following resection, the cut surfaces of the fragments are often irregular. To level off these surfaces at a right angle to the axis of the femur, the cutter shown in Figure 3, *d* is used. If the medullary canal of the involved fragment is wider than the pole of the cutter, an adapter may be placed on the lead pole to keep the cutter centered in the canal and in the opening in the spongiosa of the greater trochanter. A selection of adapters of various diameters should be available (Fig. 3, *n*). There also should be a selection of lead poles of various lengths (Fig. 3, *l*), for in canals of different proportions poles of different lengths are required to hold the cutter parallel to the longitudinal axis. By these instruments the resected ends of the fragments may be prepared so that they may be placed in precise end-to-end apposition at a right angle to the axis of the femur. However, since it is sometimes difficult to level off the broader surface of the upper fragment, it is in general better to use the conical method of apposition rather than the flat method. In the conical method, one of the surfaces is shaped into a cone while the other is hollowed out. There are two advantages of using this type of apposition: it results in more precise and reliable fixation of the fragments and it provides a larger surface for the formation of endosteal callus. The lower end of the upper fragment is shaped concavely by the cutter shown in Figure 3, *e*, while the upper end of the lower fragment is shaped convexly by the cutter shown in Figure 3, *f*. In order to ensure that the cone on the upper fragment will be centered, it is necessary to use an adapter, the size of the adapter being determined by the size of the medullary canal. In using the conical method of apposition, it must be remembered that this procedure results in further shortening of the femoral shaft.

When the medullary canal has been prepared and apposition of the resected surfaces of the fragments obtained, the outer nail may be inserted. The nail is inserted through the upper fragment into the lower fragment, care being taken to prevent rotation of the fragments. Before the outer nail is driven firmly into place, the central nail is inserted, the square nut being tightened (by means of the wrench shown in Figure 3, *i*) until the jaws of the outer nail are opened far enough to fix the fragments. The head of the outer nail is then screwed firmly into place by means of the wrench, following which, if the central nail appears to be the right length, it too may be screwed firmly into place. The length of the central nail may be considered satisfactory if, when it is firmly screwed in, the jaws of the outer nail are opened wide enough so that their notched ends are forced into the sides of the medullary canal. There is no way of determining exactly in advance what length central nail will be appropriate; this can only be determined by actual trial.

With the nail inserted, the main part of the operation is complete. The superfluous periosteal tissue is then folded and sutured, and the other layers are sutured in the conventional manner. Assuming absolute fixation, the main condition necessary to obtain prompt fusion is precise apposition of the fragments; aside from this condition the extent of the surfaces placed in apposition is the most important factor. In the first two patients in our series the surfaces of the resected bones were leveled off at right angles to the axis of the femur, with the result that the areas placed in apposition were relatively small (Figs. 5-A through 6-C). When the surfaces are shaped for conical apposition, the areas placed in contact are much larger. Another distinction between the two types of apposition is the fact that when two flat surfaces are placed in apposition, the pressure resulting from weight-bearing falls largely on the inner side of the fragments; while, when a rounded

surface and a hollowed surface are fitted together, the pressure from weight-bearing is distributed more equally on both sides. In the two patients in whom flat surfaces were placed in apposition, fusion was obtained more rapidly on the inner side, where the pressure exerted by weight-bearing and walking was greatest. Precise apposition of the fragments is most important because of the nature of callus formation, for the endosteal callus plays a more significant role in healing than the periosteal callus, which forms first.

Thompson, Straub, and Campbell, in a discussion of intramedullary nailing, described fourteen postoperative complications which had occurred following surgical shortening of the lower limb in eleven patients. They had used the Küntscher nail to obtain immobilization but had had to perform twelve further operations before healing had been obtained. On the basis of this series they had concluded that the Küntscher nail is not an acceptable means of obtaining immobilization following surgical shortening of the femur. In contrast to this, the author's nail appears to be entirely satisfactory as a means of obtaining immobilization following resection of the femur. Its value in traumatic injuries of the femur is yet to be proved, however.

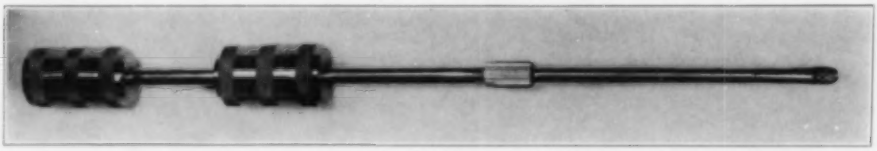

FIG. 4

An extractor, the end of which has been screwed into the head of the outer nail. The roller at the end is stationary, while the other roller is movable. This device may be used to knock the central nail out of the outer nail.

During the fifteen years prior to 1954, eighty-one patients had been treated by femoral shortening at the Olomouc Orthopaedic Clinic. In sixty-four of these patients oblique resection in the intertrochanteric region had been done and fixation had been obtained by means of wires and nails [11]; in seventeen of the patients transverse sectioning in the mid-femur had been done and fixation had been obtained by the insertion of central bone grafts and the use of wire bullets [1]. No serious complications had been noted in any of these patients. In the first group of sixty-four patients, there had been three instances of severe atrophy of the proximal portion of the femur. In the second group, there had been one instance of infraction of the central graft; this had occurred four months after the operation as a result of the patient's falling. These essentially non-significant complications healed completely following immobilization in plaster casts.

One of the great disadvantages of these two methods of treatment is that they require a long period of immobilization in a plaster cast. The limbs of the patients in the first group were immobilized for at least two months, while those of the patients in the second group were immobilized for at least four months.

In all the cases in this series, there were no complications during the postoperative course of the patient. The limb was placed in a Braun splint without immobilization. It was recommended that the patient begin active exercising of the limb as soon as possible, first by contracting the muscles, then by bending the hip and knee and by raising the flexed limb, and finally by raising the extended limb. A few days after the operation, when the postoperative pain had vanished, the patients were allowed to get up and to walk about using crutches as a protection against falling. The patients were not hindered from fully using their limbs according to their desires and ability. Our first patient began to walk in an unusually short time, while the others began partial or full weight-bearing in the first or at least the second or third week after the operation. Rehabilitation of the patients progressed rapidly. In the third week one of our patients was able to climb a double ladder, descending on the opposite side, and in the fifth week she could jump rope

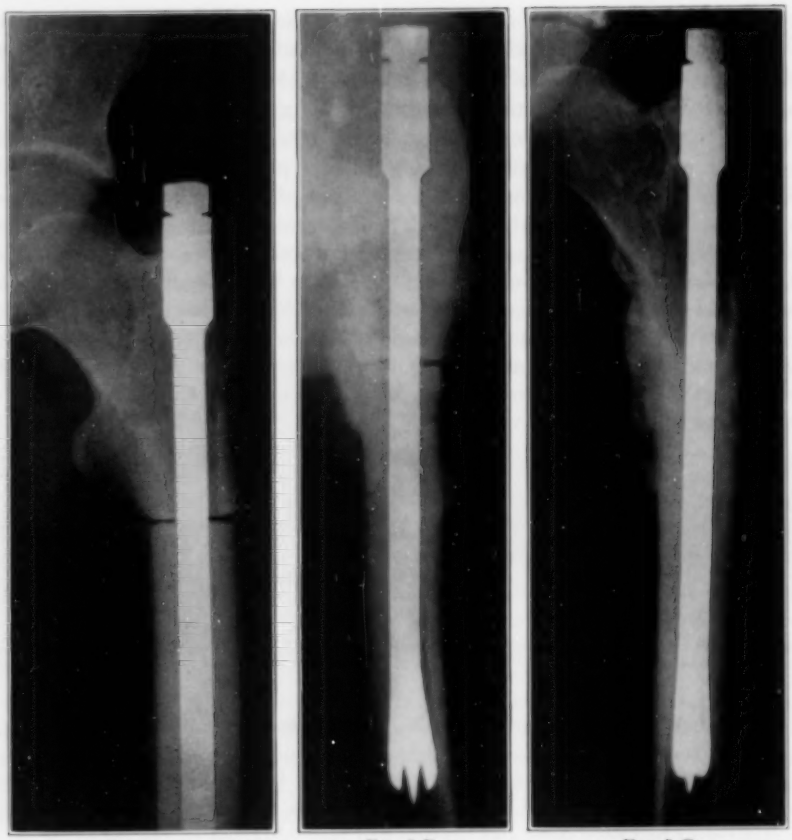

FIG. 5-A FIG. 5-B FIG. 5-C

Fig. 5-A: Case 1. Z. L., operated upon November 8, 1954. Roentgenogram made immediately after the operation.

Fig. 5-B: Roentgenogram made March 15, 1955. The endosteal and periosteal callus formed more rapidly on the inner side, where greater static pressure was exerted during weight-bearing. The apposition of the resected surfaces was imperfect.

Fig. 5-C: Roentgenogram made October 6, 1955, eleven months after the operation. Solid union has been obtained. In the region of the head of the nail ossification occurred as the result of movements of the head. The nail was later removed.

and dance. Passive exercises, massage, and other means of physical therapy were not used in any of our cases. The progress of the healing was followed by means of roentgenograms. The first stage in the healing was the development of a large amount of periosteal callus. The shape of this new callus was extremely irregular as a result of the irregular folding of the excess periosteum. Endosteal callus formed first on the inner portions of the resected bone ends of the femur, where the pressure exerted by weight-bearing was most intensive. On the outer portions of the resected bone ends the callus formed more slowly. On the basis of these findings we concluded that healing of the lesion in our series occurred more rapidly in the region upon which direct pressure was applied. Bones are broken as the result of the application of torsional or bending forces or by a combination of these forces (including the force produced by reflex contraction of the muscles); it would seem that healing of a broken bone would be more rapid if the opposite force, compression, were used to promote its healing.

There are still many orthopaedists who advocate the exclusion of any pressure whatsoever across the fracture surfaces. In our series, the application of pressure resulted

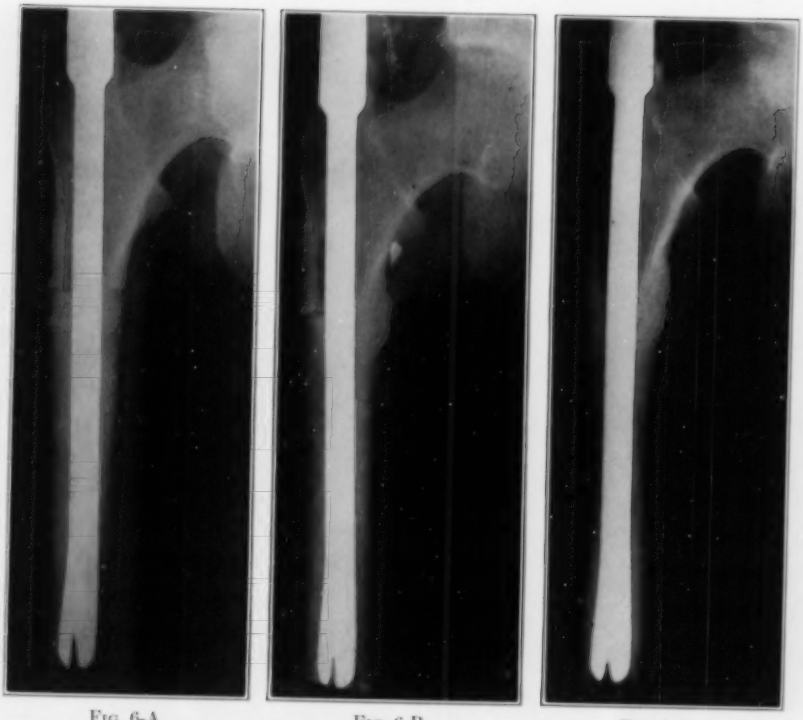

FIG. 6-A FIG. 6-B FIG. 6-C

Fig. 6-A: Case 2. S. J., operated upon December 7, 1954. Roentgenogram made immediately after the operation.

Fig. 6-B: Roentgenogram made March 2, 1955, three months after the operation. Endosteal and periosteal callus formed more rapidly on the inner surface, where there was greater static pressure during weight-bearing. The apposition of the resected surfaces was almost perfect.

Fig. 6-C: Roentgenogram made October 6, 1955, ten months after the operation. Solid union has been obtained. The nail was removed October 8, 1955.

in neither bone necrosis nor the eventual development of pseudarthrosis; on the contrary, healing occurred more rapidly. It is not my intention to discuss the pathological nature of the healing of fractures, but rather to show that the application of direct vertical pressure produces not only more rapid healing but also firmer healing. This is not true in oblique or spiral fractures, in which the direction of the plane of the fracture makes it impossible to apply pressure by means of a static load.

REMOVAL OF THE NAIL

Up to this time we have removed the nail in four cases. In the first case, the nail was removed eleven months after the operation. After the central nail had been withdrawn, the outer nail could be easily removed without instruments through a short incision over the greater trochanter. In the second and third cases it was necessary to use an extractor (Fig. 4), but only a few light taps by this instrument were sufficient to obtain easy removal. In the fourth case, the nail was removed without use of the extractor. In the second and third cases there were adhesions about the nail in the region of the resection. In the second case the nail was removed ten months after the operation; in the third case it was removed after nine months; and in the fourth case it was removed after seven months.

Histological study of these four cases revealed that the nail was generally surrounded by connective tissue with hyaline degeneration. We were interested in the adherence of

FIG. 7-A

FIG. 7-B

FIG. 8-A

FIG. 8-B

Fig. 7-A: Case 3. P. B., operated upon January 22, 1955. Roentgenogram made immediately after the operation. Conical apposition was secured, the resected end of the upper fragment being concave and that of the lower fragment being convex. By the use of conical apposition, a larger surface for the formation of endosteal callus and better fixation of the proximal fragment were obtained.

Fig. 7-B: Roentgenogram made October 20, 1955, nine months after the operation. Solid union has been obtained. The nail was removed October 28, 1955.

Fig. 8-A: Case 4. G. J., operated upon June 7, 1955. Roentgenogram made immediately after the operation. Conical apposition has been obtained. The upper fragment is in good position.

Fig. 8-B: Roentgenogram made March 5, 1956, nine months after the operation. Solid union has been obtained. An ossified bursa developed about the head of the central nail. Note the extensive hypertrophy which developed in the region of the jaws as a result of the pressure from the jaws. The nail was slightly bent. It was removed April 6, 1956.

the connective tissue to the central portion of the nail and to the distal end of the nail between the opened jaws. Details concerning this finding are given in the case histories. We were also interested in the new tissue which formed about the head of the nail as a result of its movements within the soft gluteal tissues during walking and exercising. Close to the head a bursa formed and even ossified (Figs. 5-C, 8-B, 10-B, and 11-C). In the wall of the bursa there were found bundles of fibrous tissue, most of which showed hyaline degeneration. A similar condition was found in the tissue at the distal end of the nail between the jaws, a region in which no ossification occurred during the seven to eleven months between the operation and the removal of the nail.

CASE HISTORIES

CASE 1. The first patient was Z. L., a twenty-year-old stockman (Figs. 5-A, 5-B, and 5-C). His right limb was eleven centimeters shorter than the left limb as a result of old hip disease.

The second day after the operation he had no complaints and could voluntarily lift the limb upon which the shortening had been performed. The second night after the operation he lifted his limb off the splint, got out of bed, and went into the next room to have a smoke. The third day he could actively flex, extend, and lift the limb, and on the fourth day he got up again and walked around his room. Thereafter he walked regularly, using crutches to avoid complete weight-bearing. The eleventh day he walked without using crutches, and by the twenty-sixth day he had normal mobility of his knee and hip and could lift his limb

FIG. 9-A

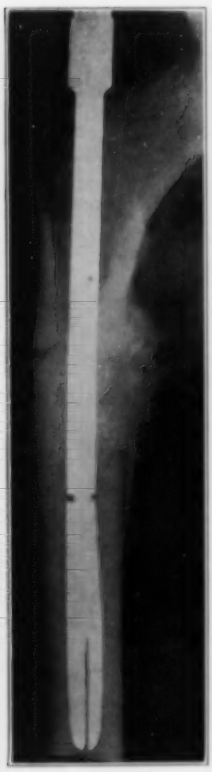

FIG. 9-B

FIG. 10-A

FIG. 10-B

Fig. 9-A: Case 5. H. A., operated upon September 17, 1955. Roentgenogram made immediately after the operation. Both the resected ends were conically milled, but the end of the upper fragment was not milled sufficiently so that the resected end of the lower fragment could not be fully inserted. The roentgenogram shows a second fault in the surgeon's technique: the jaws of the nail selected are too long with the result that their ends began to approximate.

Fig. 9-B: Roentgenogram made January 2, 1956, four and one-half months after the operation. Abundant periosteal and endosteal callus has formed in the area of resection. Because the jaws of the nail could not expand in the narrow medullary canal, they broke when the central nail was inserted. A nail with short opening jaws should have been used.

Fig. 10-A: Case 6. R. Z., operated upon October 7, 1955. Roentgenogram made the day after the operation. The resection, the apposition of the fragments, and the insertion of the nail into the trochanter have all been done correctly.

Fig. 10-B: Roentgenogram made March 1, 1956, four and one-half months after the operation. Endosteal and periosteal callus were well formed, especially on the inner side where there was increased pressure (this patient could walk with full weight-bearing on the shortened limb). The bursa about the head of the central expanding nail has ossified.

against resistance. At that time he said that he had slight pain in the distal third of the femur. On the thirtieth day a large formation of callus could be palpated. The patient was now walking without support or complaints. On the forty-sixth day he was sent home at his own request, follow-up being continued by monthly check-ups. At home he began riding a bicycle.

On October 8, 1955, eleven months after the operation, the nail was easily removed, without instruments, through a short incision. The surface of the nail showed no corrosive or other changes. After removal of the nail, the ossified tissue which had surrounded the head of the nail was cut out.

Histological findings: The tissue on the surface of the bony callus which had adhered to the middle portion of the outer nail showed hyaline degeneration and moderate inflammatory changes. The tissue on the surface of the callus at the distal end of the nail, between the opening jaws, also showed hyaline degeneration.

CASE 2. S. J., a twenty-year-old nurse (Figs. 6-A, 6-B, and 6-C) had a shortening of the left limb of five centimeters as a result of old hip disease. On December 7, 1954, surgical resection of the right limb was done, five centimeters of bone being removed.

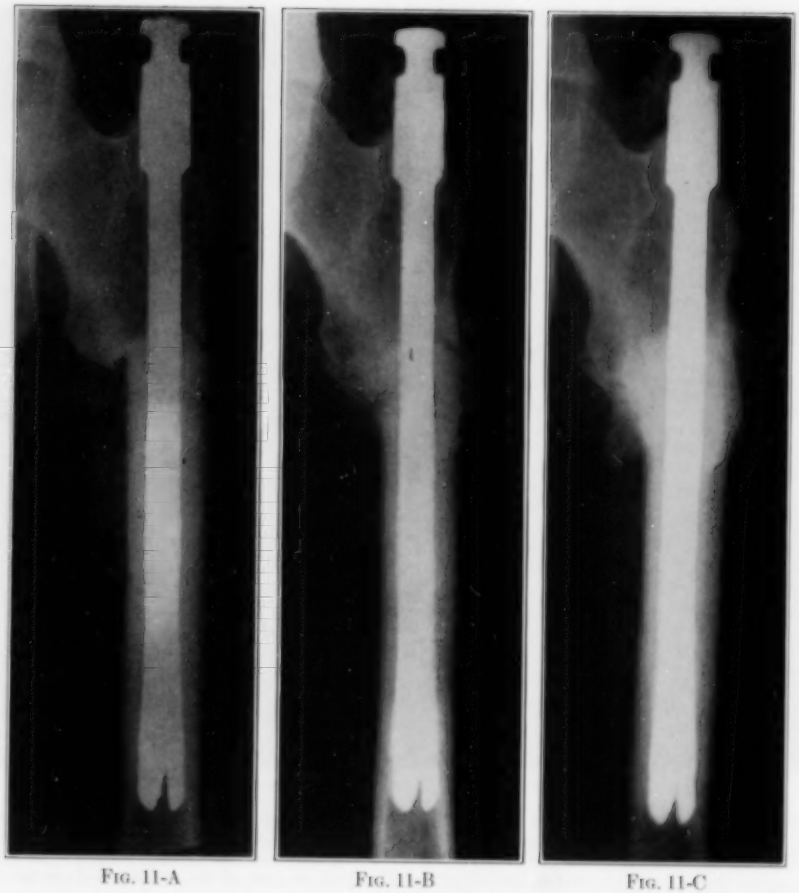

FIG. 11-A FIG. 11-B FIG. 11-C

Fig. 11-A: Case 7. C. R., operated upon November 10, 1955. Roentgenogram made the day of the operation.

Fig. 11-B: Roentgenogram made January 10, 1956, two months after the operation. Extensive periosteal callus has formed, and there is more endosteal callus on the inner side, where the greatest pressure has been exerted.

Fig. 11-C: Roentgenogram made April 26, 1956, four and one-half months after the operation. Solid union has occurred; this represents the shortest period required for healing in this series. Slight ossification is evident on the inner side of the nail. A shorter central nail would have been preferable.

For a few days after the operation, the patient complained of pain. On the fifth day she could actively flex the hip and knee as far as 90 degrees, and on the seventh day she began to walk using crutches for support and complaining only a little. Eleven days after the operation she could fully use the right lower limb, and three days later she had almost no complaints. On the twenty-second day she began to walk without crutch support and to attempt to climb a standing ladder. On the thirty-fifth day she succeeded in climbing the ladder and also could jump rope and dance. She was then sent home with directions to return at regular intervals for follow-up.

On October 8, 1955, ten months after the operation, the nail was removed by means of an extractor. Only a few hits of the instrument were necessary to free the nail. The surface of the nail was smooth and showed no changes. At this same operative session a newly formed secondary bursa was removed from the area of the head of the central nail. The wound was then sutured.

Histological findings: In the tissues which had surrounded the head of the nail there were bundles of fibers which were largely degenerated. Surrounding the veins were non-significant chronic inflammatory infiltrates of a non-specific character. The tissue from between the distal jaws of the removed nail was of a fibrous nature and showed little cellular or hyaline formation. The more cellular portion of this tissue showed evidence of chronic progressive inflammation of a non-specific character.

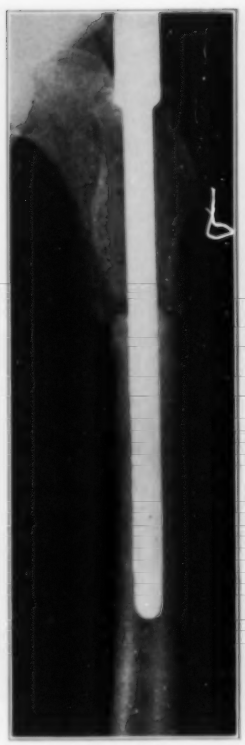

FIG. 12-A

FIG. 12-B

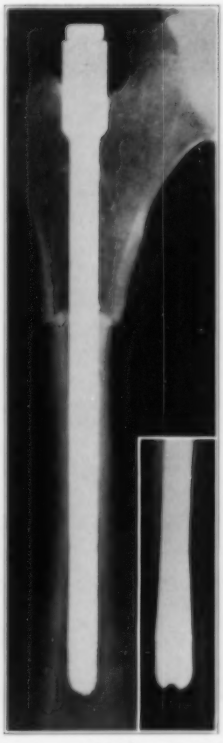

FIG. 13

Fig. 12-A: Case 8. V. V., operated upon March 1, 1956. Conical apposition was secured. The outer nail was exactly the same size as the narrow medullary canal, with the result that the jaws of the nail could not be opened. Because of evidence of beginning distraction, the limb was kept in a plaster cast for four weeks.

Fig. 12-B: Roentgenogram made June 4, 1956.

Fig. 13: Case 9. K. A., operated upon May 5, 1956. The lengths of both the outer nail and the central expansive nail were correct. The opening of the jaws, which cannot be seen in the anteroposterior roentgenogram, is shown in the insert, which is a portion of an oblique roentgenogram.

CASE 3. P. B., an eighteen-year-old student (Figs. 7-A and 7-B), had a talipes deformity of the left foot and a shortening of the left limb of ten centimeters as a result of poliomyelitis. On January 22, 1955, surgical resection was done on the right lower limb, eight centimeters of bone being removed.

By the third day after the operation the patient had no complaints when lying down; only when she moved did she have pain in the hip and knee. On the fifth day the limb could be passively lifted, and on the ninth day it could be actively moved even against resistance. Ten days after the operation the patient got up and walked with the aid of a moving support. Five days later she could walk with considerable weight-bearing when supported by crutches. On the thirtieth day, still using crutches, she could walk with full weight-bearing on the surgically shortened limb. The post-poliomyelitic and post-surgical condition of the left limb hindered the rehabilitation of this patient as regards walking. She was sent home November 3, 1955, a regular follow-up program being prescribed.

On October 28, 1955, eight months after the operation, the nail was easily removed by means of an extractor. The surface of the nail was found to be quite smooth. At the same operative session the secondary connective tissue which had formed about the head of the nail was removed. The wound was then sutured.

Histological findings: Examination of a portion of the bursa that had developed in the region of the head of the nail revealed dense connective tissue that locally merged into chronic granulation tissue of an unspecified character. Chronic granulomatous tissue containing deposits of hematoidin and hemosiderin was found in the region of the distal portion of the nail.

CASE 4. G. J., a sixteen-year-old student (Figs. 8-A and 8-B), had talipes calcaneus of the left foot and a shortening of seven centimeters of the left limb as a result of poliomyelitis. On June 7, 1955, resection of seven centimeters of bone was done on the right lower limb.

FIG. 14-A

FIG. 14-B

FIG. 15

Fig. 14-A: Case 13. B. A., operated upon June 2, 1956. This patient had a subtrochanteric fracture of the femur as a result of a non-malignant cyst. Preoperative roentgenogram made May 25, 1956.

Fig. 14-B: Roentgenogram made June 8, 1956. In order to fill the defect in the medullary canal, we used bone taken from the patient in Case 12, upon whom a femoral shortening operation had been done the previous day. The main portions of the resection surfaces were shaped conically. The apposition secured was not precise, but the defect in the canal was nevertheless well filled.

Fig. 15: Case 14. K. B., operated upon June 18, 1956. Postoperative roentgenogram.

Four days after the operation the patient was entirely comfortable when lying down. On the seventh day he could actively bend the knee and hip, and on the tenth day he could move the limb even against resistance. Despite the fact that he was without pain at this time, he still could not walk, for three weeks previously triple resection of the tarsus had been done on the left foot. Twenty-nine days after the resection he began to walk with crutches, his left limb in a plaster cast with a stirrup. On the forty-second day, the cast was removed, and on the next day he began walking with full weight-bearing, still using crutches. He was sent home August 4, 1955, a regular follow-up program being prescribed.

On April 6, 1956, ten months after the shortening, the nail was removed, without instruments, and the ossified tissue in the region of the head of the nail was cut out. The surface of the nail was quite clean and showed no evidence of erosion. The wound was sutured.

Histological findings: Examination of the tissues in the region of calcification revealed local areas of dense hyaline connective tissue which contained layers of profuse histiocytic infiltration, some unspecified granulomatous tissue, and fragments of necrotic bone. Some of the histiocytes contained an iron pigment.

CASE 5. H. A., a hairdresser twenty-two years old (Figs. 9-A and 9-B), had congenital hypoplasia of the left lower extremity and scoliosis of the thoracolumbar spine. She had previously been treated by spondylodesis of the lumbar vertebrae. The left limb was four centimeters shorter than the right. On September 17, 1955, surgical shortening was performed on the right side, four centimeters of bone being resected.

By the fifth day after the operation the patient had no pain and could exercise the hip and knee joints. By the tenth day she had a full range of motion. On the fifteenth day she got up and walked, using crutches and being very careful in placing weight on the surgically shortened limb. Twenty-three days after the operation, she could walk with almost full weight-bearing. She was sent home November 3, 1955, a regular follow-up program being prescribed.

At one check-up we found a fracture of one of the jaws of the outer nail. This had occurred because an

unsuitable nail with long jaws had been used in a narrow intramedullary canal. Sufficient callus had formed, however, and the patient walked without pain.

CASE 6. R. Z., a manager, thirty-two years old (Figs. 10-A and 10-B), had poliomyelitic talipes equinovarus of the left foot. He had previously been treated by triple arthrodesis. The left limb was five centimeters shorter than the right. On October 7, 1955, shortening of the right limb was done, with resection of five centimeters of bone.

Three days after the operation the patient had no complaints and could move the hip and knee actively. On the tenth day he had a full range of motion. Walking was not possible at this time, however, because of the tarsal resection which had been performed on the left foot four weeks previously. The surgically shortened limb was placed in a plaster cast. On the twenty-first day a stirrup was attached to the cast, enabling the patient to walk when supported by crutches. Thirty-four days after the operation the cast was removed from the paralyzed left limb and the patient began to walk, placing his full weight on this limb, but avoiding full weight-bearing on the resected limb. On the forty-ninth day, he walked with full weight-bearing on both limbs. He was sent home December 15, 1955, with directions to return for regular follow-up.

CASE 7. C. R., a thirty-five-year-old worker (Figs. 11-A, 11-B, and 11-C), had a shortening of the right limb of seven centimeters as a result of old hip disease. On November 10, 1955, resection of the left limb was done, six centimeters of bone being removed.

Five days after the operation the patient had no pain and began to exercise the limb through all ranges of motion. On the fourteenth day she got up and walked with the aid of a moving support. Two days later she walked with the aid of crutches, placing only slight weight on the resected limb. Thirty days after the operation, she walked, still with crutches, but with full weight-bearing. She was sent home on December 24, 1955, with directions to return for follow-up.

CASE 8. V. V., an official, twenty-three years old (Figs. 12-A and 12-B), had a shortening of the right lower limb of eight centimeters as a result of old hip disease. On March 1, 1956, resection of the left lower limb was done, eight centimeters of bone being removed.

Three days after the operation, when the pain had disappeared, the patient began to exercise his limb. On the fifth day he could actively move the hip and knee, and on the seventh day he could externally rotate the limb. At this time roentgenograms revealed that there was slight distraction of the fragments; a plaster cast was therefore applied, the knee and hip being flexed at right angles. Thirty-seven days after the operation, the cast was removed. During the next few days the patient exercised the limb, and on the fortieth day he began to walk.

CASE 9. K. A., a dressmaker thirty-three years old (Fig. 13), had paresis of the left lower extremity and talipes equinovarus of the left foot as a result of poliomyelitis. The left limb was 4.5 centimeters shorter than the right. Triple arthrodesis of the tarsus had previously been done. On May 5, 1956, 4.5 centimeters of bone was resected from the right lower extremity.

On the fifth day following the operation the patient began quadriceps exercises of the resected limb. At this time she complained of aching in the region of the resection. Ten days after the operation she could flex the hip and knee and could sit. Four days later she began walking, using crutches and placing only slight pressure on the right lower limb. She complained that her right knee ached when she walked. Ambulation was difficult because of the cast which had been placed on the left lower limb following the tarsal resection. Three weeks after the operation she placed only about half her weight on the resected limb. On the thirty-first day she fell while walking. There was increased pain in the knee and in the area of the resection, but roentgenograms revealed no evidence of infraction or fracture. Three days of bed rest with compresses was prescribed. Thirty-six days after the operation she began walking again, but by June 30, she still required support while walking and complained of pain in the right knee. The application of pressure in the area of resection caused aching. An extensive amount of callus had developed.

CASE 10. H. A., an accountant twenty-three years old, had a shortening of the right lower limb of 5.5 centimeters as a result of old hip disease. On May 15, 1956, resection of the left lower limb was done, 5.5 centimeters of bone being removed.

Five days after the operation, the patient, having no pain, began flexion exercises of the knee and hip. On the sixth day he sat up in bed. On the ninth day he walked for the first time, using crutches and placing little weight on the resected limb; he had no complaints. He was sent home June 19, 1956, at which time he was able to walk about in his room for a short time with no supports and with full weight-bearing on his left lower limb.

CASE 11. J. A., a dressmaker twenty-two years old, had a shortening of the right lower limb of nine centimeters as a result of osteomyelitis of the hip. On June 1, 1956, resection of the left lower limb was done, nine centimeters of bone being removed.

Five days after the operation the patient could lift the shortened limb. Following extraction of the stitches on the ninth day she began to walk with support. She complained that weight-bearing caused pain in the right knee. By the fourteenth day she could place almost half her weight on the resected limb, and by the twentieth day she could walk using crutches, with full weight-bearing on both limbs. She was sent home on June 29, 1956, having been directed to return for follow-up in four weeks.

Case 12. V. E., a seventeen-year-old clerk, had paralytic talipes equinovarus of the right foot and a shortening of the right lower limb of three centimeters as a result of poliomyelitis. On June 1, 1956, 4.5 centimeters of bone was resected from the left lower limb.

As early as the second postoperative day the patient had no pain. On the fourth day she began active quadriceps exercises, and on the tenth day, following extraction of the stitches and healing of the wound, she stood beside her bed. On the eleventh day she walked using crutches, and three days later, she began full weight-bearing on the resected limb with no pain. Her right lower limb was still in a plaster cast because of the triple arthrodesis previously performed. She was sent home June 30, 1956, follow-up visits having been prescribed.

Case 13. B. A., a dressmaker thirty-three years old (Figs. 14-A and 14-B), had a pathological subtrochanteric femoral fracture as a result of a non-malignant cystic lesion of the right femur. On June 2, 1956, osteosynthesis of the femur was obtained by means of the nail, the defect in the canal being filled with a homogenous graft obtained from the patient in Case 12.

Five days after the operation the patient had no complaints and began to exercise the femoral muscles. On the eleventh day she sat up in bed. Fifteen days after the operation she began walking, using crutches and placing little weight on the right lower limb; walking in this manner caused no pain, but because a bone graft had been placed in the cavity, full weight-bearing was not yet allowed. Following the operation this patient received 500 cubic centimeters of blood in two transfusions.

Case 14. K. B., a seventeen-year-old mechanic (Fig. 15), had paresis of the left lower extremity and paralytic talipes equinovarus of the left foot as a result of poliomyelitis. The left limb was seven centimeters shorter than the right. On June 18, 1956, resection of the right lower limb was performed, seven centimeters of bone being removed.

The patient had no pain on the second postoperative day, and on the sixth day he began vigorous exercises of the quadriceps muscle and of the hip and knee joints. Ten days after the operation, he could walk using crutches and could stand with full weight-bearing on both lower limbs. Walking was difficult because of the cast on his left lower limb, applied following triple arthrodesis. The patient is still hospitalized.

SUMMARY

From November 1954 to June 1956, a period of one and one-half years, fourteen patients were treated at our clinic by means of the intramedullary nail designed by the author. In thirteen patients the lower limb had been surgically shortened at least four centimeters, and in the fourteenth patient (Case 13) pathological fracture of the femur as a result of a cyst had occurred. We regret that we were not able to use this nail to treat traumatic injuries of the femur. Because the nail has not been used in such injuries, this paper must be considered a preliminary report. Further study is needed to determine the wider indications for the nail.

In the first four patients in our series, healing has occurred and the nail has been removed, while in the remaining patients healing is progressing satisfactorily and there have been no secondary complications. In all our patients penicillin was used both before and after the operation. Blood transfusions were necessary in only one patient (Case 13). In this case two transfusions of 250 cubic centimeters each were given eight and ten days after the operation; as a result of this treatment, the postoperative anaemia was controlled. As regards the dimensions of the nails, we used the nail with a diameter of ten millimeters in all the patients but two; in these two patients (Cases 10 and 14) we used a nail with a diameter of twelve millimeters. It seems that nails of either of these two diameters will be adequate in most cases. A greater variety in length of the nail is necessary, however, especially of the central nail. Before the operation we tried to estimate, by study of the roentgenograms, the appropriate dimensions of the nail to be used.

Note: The assistance of Dr. K. Wagner and Dr. O. Juráš, both assistants in the Department of Orthopaedic Surgery at Olomouc, and of Mr. A. Skurský and Mr. J. Pešák from Přerov is gratefully acknowledged.

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Claw-Hand Caused by Paralysis of the Intrinsic Muscles

A Simple Surgical Procedure for its Correction

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Lesions of the ulnar nerve, or of both the median and ulnar nerves, result in claw deformities of the fingers. In this condition there is hyperextension of the metacarpophalangeal joints and flexion of the interphalangeal joints caused by loss of the function of the intrinsic muscles which, normally, extend the interphalangeal and flex the metacarpophalangeal joints. The loss of the flexor function of the interossei causes loss of lateral motion and usually results in the muscle imbalance known as claw-hand. It is true that the extrinsic muscles are able to compensate for the loss of the intrinsic muscles if hyperextension of the metacarpophalangeal joints is prevented [6]. In this condition the long extensors can produce full extension of the interphalangeal joints, and the long flexors can produce complete flexion of the metacarpophalangeal joints.

Although the intrinsic function of flexion and extension of the fingers can be performed by the extrinsic muscles, this compensation does not apply to the extensors which carry out the lateral motion of the fingers.

Patients with a single lesion of the ulnar nerve or of both median and ulnar nerves, in

Fig. 1

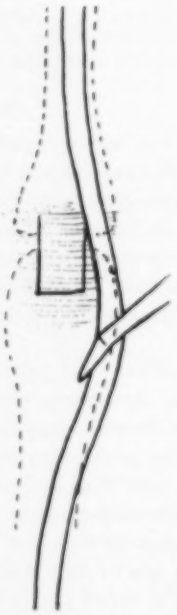

Fig. 2-A

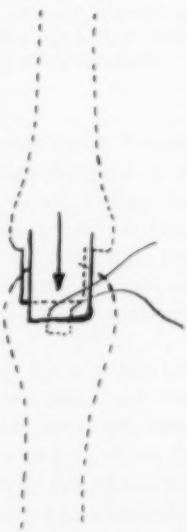

Fig. 2-B

Fig. 1: Longitudinal incisions over the flexor tendons on the volar aspect of the hand.

Fig. 2-A: After the synovial membrane and proximal pulley are opened and the flexor tendons are repaired, a flap with a distal base is cut from the volar tissues of the metacarpophalangeal joint.

Fig. 2-B: The flap is advanced proximally to obtain the desired shortening, limiting extension at the metacarpophalangeal joint to 160 degrees. The flap is sutured with thick silk thread No. 2.

TABLE I

Case No.	Diagnosis	Age (*Years*)	Type of Claw-Hand	Treatment	Length of Follow-up (*Months*)	Type of Work Patients Are Doing at Present, and Results	Length of Time after Capsuloplasty Patients Returned to Work and End Results
1	Section of the ulnar nerve at the hand.	30	Light clawing of the fourth and fifth fingers.	Neurorrhaphy and capsuloplasty in one-stage operation.	8	Car spare-parts dealer; excellent result.	6 mos.; no recurrence.
2	Lesion of the ulnar and median nerves at the wrist.	13	Clawing of the last three fingers (fifth finger was amputated).	Capsuloplasty of claw fingers.	13	Student; excellent result.	10 mos.; no recurrence.
3	Section of the ulnar nerve at the wrist.	15	Serious clawing of the fourth and fifth fingers with important trophic complications. No stiffness at the interphalangeal joints.	Capsuloplasty of claw fingers.	5	Cup-washer at a bar. Result was good even though partial recidivation of the clawing of the fifth finger occurred because the capsule had not been reduced tightly enough. Great improvement in the trophic lesions.	3 mos.; slight recurrence of the clawing in the little finger.
4	Section of the ulnar and median nerves at the wrist.	13	Serious clawing condition in four fingers with stiffness of the proximal interphalangeal joints.	Preoperative elastic traction; capsuloplasty.	6	Student. Good result; 15 degrees of flexion in the proximal interphalangeal joints remained.	3 mos.; partial correction of the clawing.
5	Section of the ulnar nerve at the wrist.	42	Clawing of the fourth and fifth fingers.	Neurorrhaphy and capsuloplasty in one-stage operation.	7	Carpenter; excellent result.	5 mos.; no recurrence.
6	Section of the ulnar nerve at the wrist.	6	Light clawing of the fourth and fifth fingers.	Neurorrhaphy, capsuloplasty, and transplantation of the extensor digiti proprius of the index to the first dorsal interossei in one-stage operation.	4	Complete correction of the clawing with excellent active abduction in the index finger.	3 mos.; no recurrence.
7	Section of the ulnar nerve at the elbow.	14	Serious clawing of the third, fourth, and fifth fingers with some stiffness of the finger joints.	Preoperative elastic traction; capsuloplasty.	9	Partial correction of the clawing because of stiffness in the joints. However, the patient can use the hand to do kitchen work.	6 mos.; partial correction of 20 degrees with traction; no recurrence.

FIG. 3-A

FIG. 3-B

FIG. 3-C

Figs. 3-A and 3-B: A year and a half before these photographs were made, this patient experienced a deep electrical burn of the hand and forearm, resulting in complete paralysis of the intrinsic muscles. Amputation of the little finger was necessary.

Fig. 3-C: Finger opposition was restored by a transplantation of the flexor sublimis. Complete finger flexion and extension was obtained and a useful hand resulted.

FIG. 4-A

FIG. 4-B

Fig. 4-A: Ulnar nerve paralysis resulting from a wound of the forearm. Nerve suture was done, but no recovery of intrinsic muscle function had been obtained two years later.

Fig. 4-B: Complete digital extension was possible after capsuloplasty.

whom claw-hand symptoms are absent, are not unusual. These patients are found to have a congenitally tight volar capsule of the metacarpophalangeal joint. This shortening of the capsule prevents hyperextension.

To obtain correction of the claw-hand it is necessary to limit the extension of the

FIG. 5-A

FIG. 5-B

FIG. 5-C

Fig. 5-A: Severe claw-hand resulting from a deep wound in the upper arm and immediate nerve suture. No intrinsic function had been obtained three years later.

Fig. 5-B: Good finger extension was possible after capsuloplasty, although some stiffness was present preoperatively in the proximal interphalangeal joints.

Fig. 5-C: Useful finger flexion was restored.

metacarpophalangeal joints. The operations described for the correction of palsy of the intrinsic muscles will accomplish this. Howard's procedure of bone-block of the metacarpophalangeal joints stabilizes these joints and permits the action of the extrinsic tendons.

With this in mind, a simpler method was sought to balance the joint. The bone-block technique demands time for consolidation. Bunnell's operation, although its results are excellent when performed early, is always a procedure of importance. However, it is a procedure of tendon transplantation and the condition of claw-hand does not necessarily require a tendon transplantation for its correction. This has been demonstrated by the good results obtained in patients by tenodesis [6] or by Bunnell's operation in which the superficial flexor tendons are fixed by adhesions in the forearm. In Fowler's procedure of extensor transplantation, the extensor indicis proprius and the extensor digiti quinti are split into two strands; a slip is passed through each interosseous space anterior to the transverse metacarpal ligament and is inserted into the aponeurosis. Because of the shortness of the tendons that are used, this procedure is difficult.

The author has devised a simple procedure, quickly performed, for correcting intrinsic claw-hand, which consists in shortening the volar capsule of the metacarpophalangeal joints.

Capsuloplasty is performed through longitudinal incisions over the flexor tendons (Fig. 1). A short flap with a distal base is cut from the volar tissues of the metacarpophalangeal joints (the fibers of the transverse metacarpal ligament, the glenoid fibrocartilage, and the volar capsule). This flap is drawn proximally, enough to obtain the desired shortening, and is sutured with silk thread, to produce a flexion of 160 degrees (Figs. 2-A and 2-B). The opening of the synovial membrane which surrounds the flexor tendons is essential for the performance of the operation. The proximal pulley at the metacarpal-joint level must be opened. After surgery the fingers are splinted in slight flexion for thirty days. The stitches are removed after eight days, and movement is begun at the interphalangeal joints in order to free the adhesions which develop in the flexor tendons as a result of the surgery. Early hyperextension of the metacarpophalangeal joints must be avoided.

We had excellent results in our seven patients (Figs. 3-A through 5-C). As in all compensatory operations for palsy of the intrinsic muscles, the best results are obtained

in patients whose joints have not yet become stiff. The procedure can be completed with a tendon transplantation, if necessary, to obtain abduction of the index finger.

There are several indications for this surgery:

1. When the intrinsic muscles do not recover after a neurorrhaphy;

2. In long-standing lesions of the nerves of the hand when fibrosis has already involved the muscles;

3. In lesions of the nerves of the hand which are considered irreparable because of the degree of the extension;

4. In claw-hand resulting from destruction of the intrinsic muscles by trauma, infections, and other causes;

5. In muscular paralysis of central origin.

In most patients when the intrinsic muscles fail to recover their power after a neurorrhaphy, a compensatory operation is indicated. The simplicity of the operation which has been described and the fact that the paralyzed intrinsic muscles rarely recover their original power after the nerves have been sutured, lead us to suggest that the capsuloplasty procedure should be performed at the time that the neurorrhaphy is done. This is especially true when there is a serious claw-hand deformity, extensive destruction of important nerves, nerve lesions of long standing, or similar conditions. By this method early use of the hand is possible while healing is taking place, and stiffness in the proximal interphalangeal joint is avoided.

Ideally, this operation should be performed on a patient before the proximal interphalangeal joints have become stiff. This is true of all methods of surgery to correct this deformity. If stiffness exists, it must be relieved as much as possible by means of elastic traction, and good passive mobility secured before the operation. After capsuloplasty, the metacarpophalangeal joints should be maintained in slight flexion in plaster for five weeks. Recently we have used an even simpler method to shorten the volar capsule of the metacarpophalangeal joint. A transverse incision is made in the capsule at the joint. The contact surfaces are scraped and the edges of the capsule are overlapped slightly and sutured.

CONCLUSIONS

1. Claw-hand caused by palsy of the intrinsic muscles is corrected when slight flexion of the metacarpophalangeal joints is obtained.

2. The way to obtain this correction is to shorten the volar tissues of the joints.

3. Patients who have nerve lesions but do not have claw-hand are found to have a congenitally tight volar capsule of the metacarpophalangeal joints which prevents hyperextension.

4. The procedure can be performed at the same time as the neurorrhaphy if the surgeon considers it necessary.

5. The correction of the claw-hand should be obtained without tendon transplantation since the tendons may be necessary for tendon transfers.

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Dorsal Dislocation of the Metacarpophalangeal Joint of the Index Finger

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Dislocation of the metacarpophalangeal joint of the index finger is apparently rare. In the records of the Hospital for Joint Diseases for the years 1947 to 1953, inclusive, only two cases were found [1]. In these two cases the dislocation could not be reduced by manipulation; it was, therefore, necessary to perform open reduction, and even that was not easy. The author, in his own practice during a period of twenty years, has also encountered only two cases. One of these cases is described here; the other was seen about fifteen years ago.

A review of the literature provides further evidence that this dislocation is not common. Le Clerc, in his review of the literature from 1883 to 1911, collected only ten cases. In addition to these, he described his own case in which he had succeeded in obtaining reduction by manipulation. Polaillon, cited by Le Clerc, collected ten cases in his review of the literature in 1883. In most of the cases mentioned by Le Clerc, reduction was obtained by open operation. The author had followed the procedure proposed by the famous Farabeuf for the reduction of dislocation of the metacarpophalangeal joint of the thumb. Farabeuf had made a masterful study of the mechanism and anatomy of dislocation of the metacarpophalangeal joint of the thumb. His study of dislocation of the metacarpophalangeal joint of the index had apparently been less complete, however, for in *Précis de Manuel Opératoire* he devoted only a few lines and one drawing to this subject, and the method of treatment he recommended was the same as that for dislocation of the metacarpophalangeal joint of the thumb. It is obvious that the illustrious anatomist did not have the opportunity to observe the anatomy of dislocation of the index from the volar aspect.

In modern texts on hand surgery and on fractures and dislocations, only general statements concerning this injury are found [1, 4, 5, 7, 10]. Furthermore, no reference to this type of dislocation is found in the American and British volumes of *The Journal of Bone and Joint Surgery* for the years 1949 to 1955, inclusive.

Dislocation of the metacarpophalangeal joint of the index presents certain characteristics which make it distinctly different from dislocation of the thumb or little finger [9].

In incomplete subluxation the problem is comparatively simple. The proximal phalanx is only slightly displaced, the deformity is mild, and the finger may usually be pulled back into place by the patient himself. Complete dislocation presents a different problem, however. The proximal phalanx is displaced over the dorsum of the corresponding metacarpal, the hand is deformed, and the index is inclined toward the middle finger. In this type of dislocation closed reduction, even if performed immediately after the accident, is unsuccessful, and open reduction may be difficult unless the exact anatomy of the deformity is understood.

DESCRIPTION OF A TYPICAL CASE

The injury is produced by striking of the volar surface of the outstretched index against a resistant object. As a result of this blow, the index assumes the following characteristic position (Fig. 1). The proximal phalanx is hyperextended at the metacarpophalangeal joint and rests on the dorsum of the second metacarpal; it is also deviated toward the middle finger, overlapping slightly the radial side of this finger. The middle

and distal phalanges are slightly flexed, and the extensor tendons of the index finger are relaxed. On the volar surface of the hand there is a round regularly shaped mass, formed by the head of the second metacarpal, which is located under the stretched palmar skin just distal to the thenar eminence, between the thumb and third metacarpal. The skin is peculiarly puckered on both sides of the protruding mass, parallel to the thenar crease. This puckering, which resembles the dimpling of the skin in carcinoma of the breast, is pathognomonic and frequently presages irreducibility of the dislocation by the closed method (Fig. 1).

Lateral and oblique roentgenograms of the hand should be made as well as an anteroposterior view, for the latter alone may not demonstrate exactly the nature of the deform-

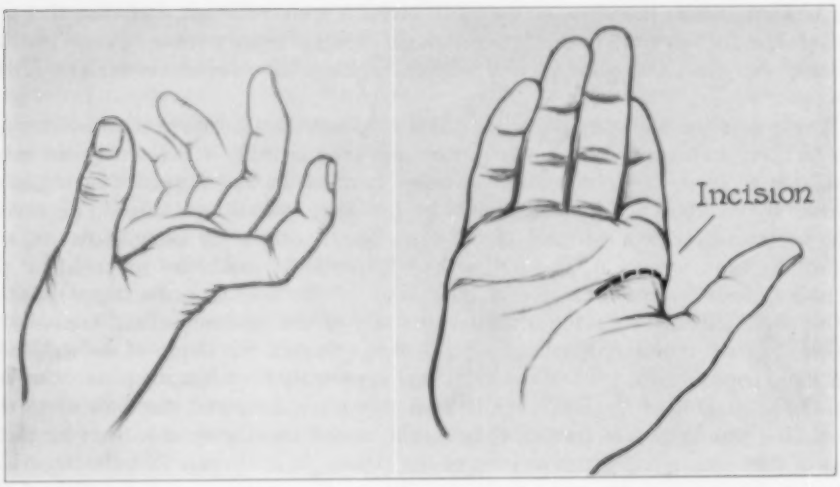

FIG. 1

Left: Lateral view of the deformity resulting from the dislocation. Right: Volar view of the deformity showing puckering of the skin, a condition which is pathognomonic of this type of dislocation. The line of incision is also shown.

ity. Typical roentgenograms (Figs. 2-A and 2-B) show that the head of the second metacarpal has been depressed into the palm of the hand, that the intermetacarpal space between the second and third metacarpals has been increased, and that the proximal phalanx has been shifted to the dorsum of the neck of the second metacarpal. The space between the phalanx and the metacarpal head is increased, and the index is deviated and overlaps the dorsum of the middle finger.

CASE REPORT

Mr. I. G. injured the index of the right hand while playing ball, the volar surface of the outstretched finger being hit by one of the players. The index immediately became displaced and could not be moved. Within about an hour the patient was admitted to the Lebanon Hospital in New York City, where a diagnosis of dislocation of the metacarpophalangeal joint was made. With the patient under general anaesthesia, the metacarpophalangeal joint was manipulated by an orthopaedic surgeon. Reduction was not obtained, however, and, therefore, on the next day (October 1, 1956) another attempt was made (by the author) to reduce the dislocation by the closed method. This attempt was also unsuccessful and was followed immediately by the performance of open reduction.

Through an incision placed over the dorsum of the metacarpophalangeal joint and extended into the thenar crease of the volar surface, the dorsal and volar aspects of the displaced joint were exposed. Although the volar fibrocartilaginous plate was cut longitudinally in order to free it from the dorsum of the second metacarpal, reduction could not be accomplished until the incision was extended volarly, revealing that the head of the dislocated metacarpal protruded through the palmar aponeurosis, where it was firmly wedged.

Division of the transverse fibers of the volar aponeurosis permitted the proximal phalanx to be restored to its usual place, which, in turn, allowed the flexor tendons to occupy their normal position in the palm of the hand. As soon as the phalanx had been replaced in its normal position, passive motion of the finger showed complete freedom of flexion and extension in all joints.

The dorsal incision was made in accordance with the method of Farabeuf. He advised that the incision be placed over the dorsum of the joint in order that the volar fibrocartilaginous plate, which is displaced with the phalanx to the dorsum of the metacarpal, may be reached. In this method, the incision is made through the dorsal apparatus of the finger parallel to the extensor tendons, following which the displaced plate may be reached.

FIG. 2-A

Fig. 2-A: Lateral roentgenogram. The head of the second metacarpal is displaced volarly, while the proximal phalanx is displaced dorsally. There is a space between the head of the metacarpal and the base of the phalanx.

Fig. 2-B: Oblique roentgenogram. The space between the second and third metacarpals is increased.

FIG. 2-B

In the case presented here, division of the plate as recommended by Farabeuf did not permit reduction. The incision was, therefore, extended to the thenar crease (Fig. 3).

In order to better understand the pathological nature of this dislocation, a careful study was made of several hands of cadavera in which experimental dislocation of the metacarpophalangeal joint of the index had been done.

NORMAL ANATOMY OF THE METACARPOPHALANGEAL JOINT

In the normal hand the anterior portion of the capsule of the metacarpophalangeal joint is reinforced by a fibrocartilaginous plate which faces the head of the metacarpal. Distally this plate is attached to the volar base of the proximal phalanx, while proximally it is loosely attached to the subcapital area of the metacarpal. On its volar surface there is a closed tunnel, the vaginal ligament, through which the flexors of the index pass. The collateral ligaments, which reinforce the capsule of the joint from the sides, blend with the anterior portion of the plate and are directed from the lateral subcapital area of the metacarpal to the sides of the base of the proximal phalanx. The looseness of the attachment of the fibrocartilaginous plate to the neck of the metacarpal and the direction of the fibers of the collateral ligaments permit normal motion of the metacarpophalangeal joint.

In the mid-palmar fascia there is a system of longitudinal fibers which extend from the wrist toward the fingers. These fibers, which are called pretendinous bands, adhere firmly to the flexor-tendon tunnels (the vaginal ligaments) over the metacarpophalangeal joints. The pretendinous band of the index finger, before connecting with the flexor tunnel, deflects to the radial side of the hand. The palmar fascia includes two groups of trans-

verse fibers. The more distal group extends across the hand just below the interdigital folds, connecting the index to the little finger and forming the natatory ligament. The more proximal group extends across the palm of the hand, connecting the pretendinous bands; this is the true superficial transverse metacarpal ligament. These two groups of transverse fibers anchor the mid-palmar fascia firmly to the radial side of the hand [6].

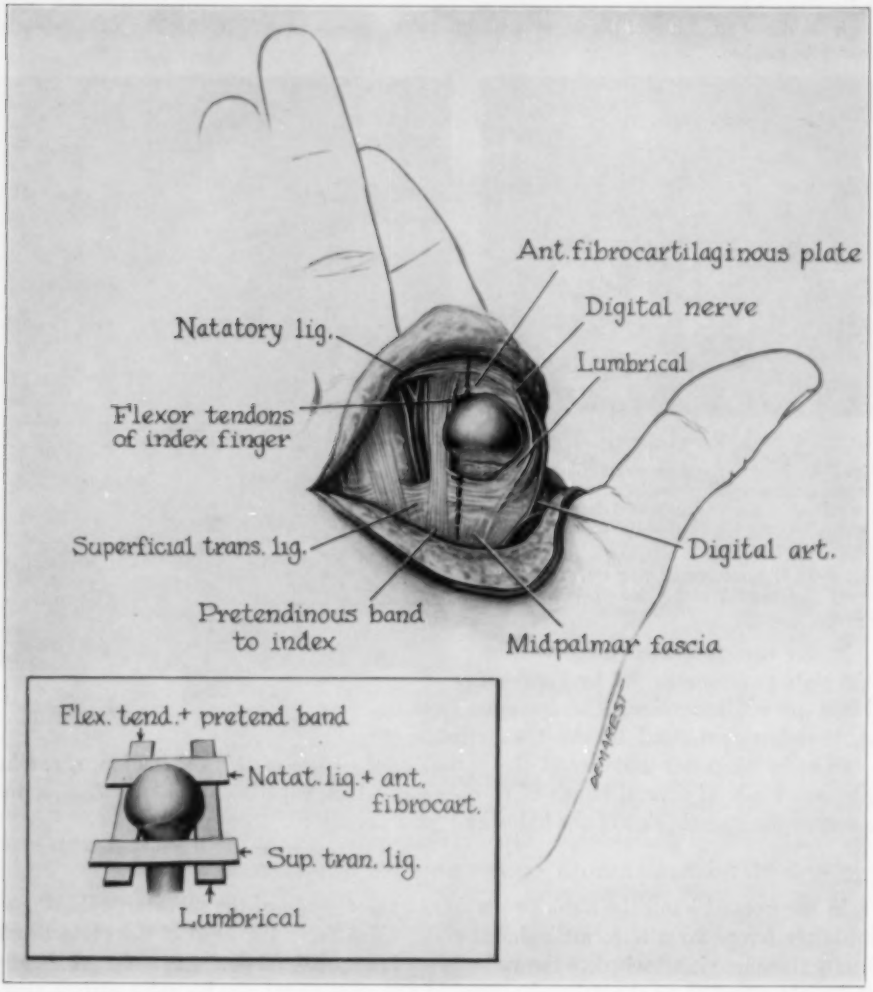

FIG. 3

The first incision exposes the area of dislocation. The second incision, made above the metacarpal head, divides the volar plate and the distal group of transverse fibers. Another incision, made below the metacarpal head, divides the proximal group of transverse fibers, freeing the head.
The insert shows, diagrammatically, the four constricting factors surrounding the head.

ANATOMY OF DISLOCATION OF THE METACARPOPHALANGEAL JOINT

When dislocation occurs, the head of the metacarpal is displaced to the radial side of the flexor tendons. This is the result of the position of the flexors, which normally extend from the wrist to the metacarpophalangeal joint at an angle of about 45 degrees, passing over the ulnar third of the head. The fibrocartilaginous plate breaks away in the region of its weakest attachment, at the neck of the volar aspect of the second metacarpal; and

the flexor tendons in the vaginal ligament and the pretendinous band of the mid-palmar fascia, which adheres to the vaginal ligament are violently displaced to the ulnar side of the metacarpal head. Following this, the fibrocartilaginous plate of the joint is displaced over the head of the metacarpal, landing on the dorsum of this bone, where it becomes wedged between the base of the proximal phalanx and the head. The lateral collateral ligaments, which are now abnormally displaced, lock the phalanx in the abnormal position typical of this dislocation. At the same time the two groups of transverse fibers of the palmar fascia hold the head of the metacarpal, the distal group (the natatory ligament, which moves with the phalanx) applying pressure to the dorsum of the metacarpal head, while the proximal group (the superficial transverse ligament, which extends across the volar aspect of the metacarpal neck) applies pressure to the volar aspect.

The course of the lumbrical muscle is changed. It now extends from the displaced flexor digitorum profundus, along the ulnar side of the metacarpal head, across the volar aspect of the neck of the metacarpal, to the area of its normal insertion, which is on the radial side of the dorsal extensor apparatus of the index. As a result of this change in course, it functions as an extensor of the proximal phalanx instead of as a flexor, its normal function.

Thus, the dislocated head becomes firmly wedged between the two groups of the transverse fibers of the palmar fascia and the fibrocartilaginous plate. The radial anchorage of the transverse fibers holds the head firmly displaced on this side, while the flexor tendons with the longitudinal pretendinous band of the index hold the head locked on the ulnar side (Fig. 3, insert).

The intimate connection of the longitudinal pretendinous band and the transverse fibers of the palmar fascia with the palmar skin, which is displaced in the region of the head of the metacarpal, is responsible for the puckering of the skin. This puckering may be considered an indication of serious wedging of the metacarpal head, a condition which contra-indicates the use of closed reduction. In cases in which this puckering is present, it is better not to attempt closed reduction but rather to perform an open surgical procedure.

SURGICAL TECHNIQUE

In open reduction the incision is started in the thenar crease of the hand at the radial base of the index finger and is continued into the proximal crease of the hand (Fig. 1) where it is found that the skin stretched over the head of the metacarpal is thin. The head is then carefully exposed, revealing the following conditions. The pretendinous band and the vaginal ligament with the flexor tendons are all completely displaced to the ulnar side of the head of the second metacarpal. The displaced pretendinous band exerts a strong pull on the transverse fibers of the palmar fascia below (volarly) and on the metacarpal head above (dorsally). The branches of the digital nerve to the ulnar side of the index and to the radial side of the middle finger and the arteries are tightly squeezed between the ulnar side of the second metacarpal and the third metacarpal head. Across the volar aspect of the neck of the second metacarpal, the lumbrical muscle, as it extends obliquely from the radial side of the base of the dislocated proximal phalanx to the displaced flexor digitorum profundus tendon, is tight. The fibrocartilaginous volar plate of the metacarpophalangeal joint is wedged between the dorsal portion of the neck of the second metacarpal and the base of the phalanx (Fig. 3).

To reduce the dislocation following exposure, it is necessary to divide all the constricting bands. The first incision is made to free the constriction of the cartilaginous plate. This incision is placed parallel and radial to the vaginal ligament and extends from the free edge of the torn ligament to the junction of the periosteum with the proximal phalanx. The incision must penetrate the entire thickness of the plate. Division of the plate alone is not sufficient, however. The transverse fibers of the taut natatory ligament must also be completely divided, and following this, another longitudinal incision should be made through

the transverse fibers of the superficial transverse metacarpal ligament. This third incision, which should extend to the ulnar side of the first lumbrical muscle, releases the constriction below the metacarpal head.

That release of the fibrocartilaginous plate alone may not be sufficient is demonstrated in the case previously described. The triple incision described here (Fig. 3) frees the base of the proximal phalanx, which then returns to its normal place over the metacarpal head. This, in turn, permits the immediate replacement of the second metacarpal head in line with the other metacarpal heads, following which the flexor tendons, the vaginal ligament, and the nerves and vessels are restored to their normal positions. The wound is then closed in the accepted manner, and the finger is immobilized in functional position for about one week.

SUMMARY

1. Dislocation of the metacarpophalangeal joint of the index is rare.

2. Complete dislocation is almost always irreducible by the closed method and requires open reduction.

NOTE: The author wishes to thank Dr. H. Cohen, Associate Orthopaedic Surgeon at the Lebanon Hospital, for referring the patient with the dislocation. He also wishes to express his gratitude to Mr. Robert Demarest, the artist of the Department of Anatomy of the College of Physicians and Surgeons, Columbia University, for his drawings.

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Combined Adductor-Gracilis Tenotomy and Selective Obturator-Nerve Resection for the Correction of Adduction Deformity of the Hip in Children with Cerebral Palsy*

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In the cerebral palsy patient, the most frequently encountered deformities of the lower extremities are equinus deformity of the ankle, flexion deformity of the knee, and adduction contracture of the hip. In carrying out a comprehensive program for the rehabilitation of the cerebral palsy child in a special clinic at the New Jersey Orthopedic Hospital during the past eight years, we have learned that surgery of the extremities, when carefully planned and executed as a part of the over-all treatment, yields increasingly satisfactory results. A combined operation for the correction of adduction deformity of the hip has been developed in this clinic; this operation includes tenotomy of the adductor longus, adductor brevis, and gracilis and selective resection of the obturator nerve. It has yielded gratifying results in thirty-five of thirty-eight patients, and it is now the procedure of choice at this clinic for the correction of adduction deformity of the hip in cerebral spastic children.

The combined operation for the relief of adduction deformity of the hip is recommended only for the spastic group of cerebral palsy patients. In the evaluation of the involved extremity, the potentialities of the individual muscles must be assessed in light of the total condition of the patient. Rehabilitation of the patient will depend not only on the restoration of muscle balance in the extremities, but also on the proper alignment of the joints used in weight-bearing and the establishment of correct posture.

Adduction deformity of the hip may be caused by (1) spasticity of the adductors combined with flaccidity of the abductors, (2) spasticity of the adductors combined with overstretching or weakness of the abductors, (3) spasticity of the adductors and internal rotators, and (4) spasticity of the gracilis [1]. Careful muscle evaluation should precede the performance of any surgical procedure. This is particularly important for patients with a scissors-type deformity. In cases of pure adductor spasticity, if the patient is in the supine position, the limbs do not internally rotate when forcibly abducted. When adduction deformity is due to spasticity of the internal rotators of the hips, it is usually combined with an internal-rotation deformity. The scissors gait most often results from a hip-flexion, internal-rotation deformity in which the tensor fasciae latae is the major deforming factor. In cases of pure adductor spasticity the limbs will be brought together but will not cross unless the hip flexors are involved. It has been our experience that most long-standing adduction deformities are due to a combination of contracture of the involved muscles and their sheaths and spasticity of the involved muscles. Because of this combined mechanism, neither adductor tenotomy nor obturator neurectomy alone will be sufficient to correct the deformity; rather a combination of these procedures will be necessary. In the preoperative analysis of the adduction deformity, the status of the hip abductor muscles should be evaluated with care. Repeated testing of the glutaeus medius will often demonstrate voluntary power in the abductors, particularly after the wearing

* Read at the Tenth Annual Session of the American Academy for Cerebral Palsy in Chicago, Illinois November 19, 1956.

of braces to overcome the stretching of the abductors caused by the force of the spastic antagonist adductor muscles. The scissors deformity may be the result of an attempt by a patient with weak or flaccid glutaei medii to stabilize the lower extremities. In such a situation, adductor tenotomy and obturator neurectomy will correct the adduction deformity at the expense of eliminating the one stabilizing factor available to the patient for walking and standing. It is certainly better for the patient to walk with adduction deformities of the hips than not to walk at all. This operation, then, is contra-indicated in the presence of persistent flaccidity of the abductors of the hips.

Frequently, the gracilis muscle contributes to the adduction deformity. This is particularly true in patients with adduction deformity of the hip associated with flexion deformity of the knee. The gracilis not only adducts the thigh but also flexes the leg and, after it is flexed, assists in its medial rotation. This muscle is innervated by a branch of the anterior division of the obturator nerve. Contracture of the gracilis muscle may be elicited by a test evolved by Winthrop M. Phelps [2]. The patient is placed in the prone position with the legs flexed and the thighs widely abducted. As the legs are gradually extended, adduction of the thighs will occur if the gracilis muscles are spastic or contracted. In the combined operation used in this clinic, tenotomy of the gracilis is performed at the same time as tenotomy of the adductor longus and adductor brevis.

Since the majority of the patients who may benefit from this procedure are spastic paraplegics or quadriplegics, a bilateral technique is utilized. This operation may also be employed effectively in patients with unilateral adduction contracture associated with progressive subluxation and dislocation of the hip.

OPERATIVE TECHNIQUE

The patient is placed supine on the operating table with both limbs fully abducted and externally rotated. When the limbs are in this position, the adductor longus is under tension and so can be easily identified. After the usual skin preparation and draping, an incision is made on the anteromedial aspect of the thigh, beginning at the level of the pubis and extending distally along the line of the adductor longus. The muscle is severed close to its attachment to the pubis and is drawn aside until the adductor brevis is exposed. The anterior division of the obturator nerve may now be seen as it extends over the surface of the adductor brevis. The nerve is grasped and transected and its distal branches to the muscles are avulsed. The adductor brevis is then separated from the adductor magnus, transected at its tendinous origin from the pubis, and retracted anteriorly. The posterior division of the obturator nerve may now be identified on the surface of the adductor magnus. The nerve is stimulated, preferably by a faradic current. If the posterior division demonstrates evidence of hyperirritability, it, too, is transected and its distal muscle branches are avulsed. The origin of the gracilis is now transected. The incision is then closed and dressings are applied.

Postoperative fixation with the limb in wide abduction may or may not be necessary. In the infant, a Frejka pillow splint may be used to maintain abduction, and in the older child, plaster-of-Paris fixation or long braces with an adjustable spreader bar attached above the knees may be utilized for at least four weeks. For patients with the more severe adduction deformities, fixation in abduction at night by the use of the pillow splint or the long brace apparatus with a spreader bar is recommended for a further period of several months. Early initiation of a vigorous exercise program for the activation and strengthening of the hip abductor muscles is urged to restore muscle balance about the hips.

MATERIAL AND RESULTS

During the past eight years, thirty-eight children with adductor deformity of the hip have been treated by bilateral adductor-gracilis tenotomy and selective obturator neurectomy. In each case a vigorous program of exercises to strengthen the glutaei medii was carried out postoperatively.

The length of follow-up in this group ranged from one year, ten months to six years, nine months, the average follow-up being three years, three months. Twenty-eight patients were followed for well over three years.

At the time of operation, the average age of the patient was four years, five months, and the range was from two years, ten months to twelve years, seven months. Seventeen patients were under the average age of four years, five months.

Clinically all thirty-eight children were classified as *spastic*. Twenty-five were paraplegics, seven were quadriplegics, and six were triplegics.

The hip abductors were graded preoperatively on the basis of Lovett's system as described by Legg in 1932; 0: *gone*, no contracture can be felt; I: *trace*, the muscle can be felt to tighten but no movement is produced; II: *poor*, the muscle can produce movement if it is not operating against gravity; III: *fair*, the muscle can produce movement when operating against gravity; and IV: *good*, the muscle can produce movement when operating against resistance as well as gravity. In this series the muscles were graded as 0 in no patients, as I in four patients, as II in twenty-six patients, as III in seven patients, and as IV in one patient.

Of the thirty-eight patients in this series, thirty-five showed marked and almost immediate improvement. This improvement became more apparent as the hip abductors showed increasing strength. With few exceptions, the immediate use of long braces with attached pelvic bands was unnecessary, as walking with or without crutches was possible. The three patients who did not improve as anticipated following surgery were again subjected to careful muscle testing. It was found that in these patients lateral balance could not be established because of persistent flaccidity of the hip abductors. The three patients were continued in the training program wearing long braces with attached pelvic bands. It was felt, after re-evaluation of the musculature, that the lack of improvement was due to failure by the surgeon to recognize that the glutaei medii were flaccid zero-cerebral muscles.

The criteria used to grade the final results in this series were as follows: (1) *excellent:* the patient could walk without braces or support; (2) *good:* the patient could walk with the aid of crutches or canes but without braces; (3) *fair:* the patient could walk with the aid of crutches or canes and long or short braces; and (4) *poor:* the patient could not walk and required long braces with a pelvic band. The final results were excellent in eight children, good in twenty-two, fair in five, and poor in three.

DISCUSSION

There are many advantages in the combined procedure of adductor-gracilis tenotomy and selective obturator neurectomy. In most cases the adduction deformity of the hip is due to the combined forces of contracture and spasticity [4] of the involved muscles. (Long-standing uncontrolled spasticity results in contracture of the muscle fibers and muscle sheath.) Since adduction deformity of the hip is due to this combined mechanism, neither adductor tenotomy nor obturator neurectomy alone will correct both elements of the deformity as well as will a combined procedure. To properly correct this deformity, the hyperirritability of the spastic muscles must be eliminated and the contracted tissues must be released.

The combined operation makes prolonged postoperative immobilization of the extremities in the corrected position unnecessary and makes possible early resumption of active and functional exercises. Elimination of the spasticity in the adductors also aids in the development of muscle balance, particularly the lateral balance achieved through strong hip abductors.

The neurectomy is selective in that usually only the anterior branch of the obturator nerve need be eliminated. The posterior branch is transected only in patients with severe adduction deformities and in patients in whom the nerve shows a hyperirritable reaction

to stimulation during the operation. This selective type of neurectomy is superior to the intrapelvic obturator neurectomy. Following complete obturator neurectomy of the latter type, adduction will be provided by the pectineus muscle, which is supplied by the femoral nerve, and by that portion of the adductor magnus which is innervated by the sciatic nerve. The adductor power provided by these muscles may prove to be inadequate. Furthermore, performing two separate operations, the obturator neurectomy being done after the adductor tenotomy has been completed, becomes a much more difficult procedure, since in the second operation the scar tissue from the first operation will interfere with the proper identification of the branches of the obturator nerve.

In the combined operation, tenotomy of the gracilis and elimination of its nerve supply not only helps reduce the adduction deformity but, at the same time, removes an insidious source of knee-flexion deformity.

SUMMARY

1. Combined adductor-gracilis tenotomy and selective obturator neurectomy is recommended as the procedure of choice in the correction of adduction deformities of the hips in cerebral spastic children.

2. This operation should be preceded by a careful analysis of the muscle potentialities about the hip joints and should be followed by early vigorous exercises for the activation and strengthening of the hip abductors.

3. In this operation the adductor longus, the adductor brevis, and the gracilis muscles are transected, and a selective obturator neurectomy is performed.

4. This procedure has been completed on thirty-eight patients during the past eight years. Improvement was noted in thirty-five of these patients.

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Familial Osteochondritis Dissecans with Associated Tibia Vara*

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The purpose of this paper is to discuss osteochondritis dissecans and associated tibia vara (1) as a manifestation of a constitutional epiphyseal disturbance rather than as a separate single clinical entity and (2) as a condition in which heredity is an etiological factor. It is not the intent of the author to propose any new theories as to etiology or different methods of treatment. A small series of cases is presented.

OSTEOCHONDRITIS DISSECANS

While *osteochondritis dissecans* has been the accepted term for many years, *osteochondrosis dissecans* might well be a more appropriate term. The suffix *-itis* implies or suggests infection, whereas actually the pathological changes are more consistent with aseptic necrosis. In 1931, Wagoner and Cohn clearly described osteochondritis dissecans as a non-infectious process which involves the articular cartilage and the subchondral bone of certain long bones of the extremities and which causes sequestration from the articular bone surface of a single loose body or, more rarely, of two loose bodies which become lodged in the contiguous joint.

As early as 1856, Teale reported a case which may well have been osteochondritis dissecans. In this case a brewer had a flattened circular loose body in the right knee. He was operated upon at Leeds Infirmary in 1855. Following the operation there developed "inflammation of the joint and phlegmonous erysipelas of the thigh and buttock, which proved fatal on the sixth day." On examination of the limb after death Teale found that in the articular surface of the inner condyle there was a circular depression of about one-eighth of an inch. The removed body fitted into this depression. Teale's explanation was that "a portion of the articular cartilage, and of the adjoining layer of bone, had been injured by the accident which the patient sustained [a year before] when moving the cask; and that, by a slow process of exfoliation, extending through a period of about twelve months, the injured part was cast off and became loose in the joint, causing the pain and lameness which led him to seek for relief."

The term *osteochondritis dissecans* is attributed to Koenig (1889), who felt that the loose piece of bone had been "dissected away" from the femoral condyle.

Archer and Peterson discussed the local pathology of osteochondritis in 1930 and stated that the diagnosis can only be made by roentgenographic examination of the joint involved. They used the term *bone button* to describe the loose fragment seen in the latent stages of the condition. They felt that osteochondritis dissecans is but one phase of the deforming non-infectious diseases of adolescence.

Gray, in a discussion of the paper by Archer and Peterson, attempted to clarify the origin of the term *osteochondritis dissecans*. He stated that *dissecans* is derived from *dis-*, which means "from," and *secare*, which means to "cut off," whereas *desiccans* is derived from *desiccare*, which means to "dry up."

ETIOLOGY

Hermanson, in 1946, reported that males are affected four times as often as females and presented three cases of bilateral osteochondritis of the knee. He stated that the

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 29, 1957.

FIG. 1

Fig. 1: Photograph made July 12, 1947. The mother is not included. *Left to right:* father, H. D., sixty-one years old, with tibia vara of the left limb; older son, S. D., fifteen years old, with bilateral tibia vara; younger brother, L. D., twelve years old, with tibia vara of the right limb (the left limb showed no bowing at that time); and the daughter, R. D., eleven years old, with "normal legs." Note that they all have unusually long second toes.

FIG. 2

Fig. 2: Father, H. D. Lateral roentgenogram of the left knee. Note the degenerative changes on the condyles and under surface of the patella and the large loose body in the anterior compartment of the knee.

etiology remains unknown but that trauma is considered by most authors to be the cause.

Fairbank, writing in 1933, felt that trauma from within the joint is a likely etiological factor in cases of osteochondritis dissecans involving the medial femoral condyle. The medial tibial tubercle is the larger of the two tubercles. As a result of rotation of the tibia on the femur and the application of an external force driving the tibia inward or the femur outward, the medial tubercle is forced against the medial femoral condyle. Fairbank definitely felt that when the condition occurs in more than one member of a family, the etiological factor is still local trauma, this trauma being the result of hereditary anatomical peculiarities. A fracture of the cartilage and the subchondral bone results from the repeated local trauma of the medial tibial spine against the medial femoral condyle.

In 1925, Balensweig reported a case in which a loose body arose from the lateral femoral condyle. He felt that this loose body was the result of an osteochondral fracture which was caused by a combination of cross strain and the pull of the anterior cruciate ligament.

Ribbing, in 1955, observed that multiple epiphyseal disturbances first develop between the ages of seven and thirteen and are not clinically apparent during the first years of the disease. He stated that in his cases roentgenograms revealed anatomical variations

and anomalies in the secondary ossification centers, and he concluded that osteochondrosis dissecans may be both constitutional and traumatic in origin. A secondary or accessory bone nucleus in the medial femoral condyle may be detached during childhood, becoming partly fused to the cancellous bone but at the same time remaining partly separated by cartilage. Because there is an incomplete vascular connection between this nucleus and the surrounding cancellous bone—a phenomenon known as *locus resistentiae minoris*—the slight dislocation which is caused by mild injury or strain (including that caused by movements within the range of normal function) may result in interference in the blood supply to the bone nucleus.

In 1919, Axhausen proposed the theory of vascular occlusion as the probable explanation of osteochondritis dissecans; and later, in 1924, he concluded that osteochondritis dissecans, together with Legg-Calvé-Perthes disease, Kienbock's disease, and Kohler's bone disease, could be classified under the general term *aseptic epiphyseal necrosis*.

Wiles, in 1955, listed two principal theories: (1) the traumatic theory, according to which impaction of the patella or the tibial spine against the femur causes a fissure fracture of the affected part of the bone, and (2) the embolitic theory according to which obstruction of one of the arteries which supply the juxta-articular region of the bone and which are functionally end-arteries may cut off the blood supply, causing necrosis.

Platt, writing in 1956, stated that since the pathology of osteochondritis dissecans is so precisely and sharply defined, it is remarkable that there is still speculation as to the exact etiology of the disease. In support of the theory of trauma, Platt mentioned (1) the fact that a history of trauma is given in many cases and (2) the fact that the condition is limited to certain sites and certain joints. The sites have in common the following features: (a) they lie on a convex surface, (b) they are under pressure as a result of contact with the bone on the opposite side of the joint, and (c) they are subject to continual movement.

ETIOLOGICAL FACTOR OF HEREDITY

In 1925, Bernstein discussed the presence of loose bodies in three members of the same family and stated that he believed the condition to have a hereditary basis. He reviewed the typical history and operative findings in his cases. He felt that it was improbable that trauma was the etiological factor because of the occurrence of the condition bilaterally.

Harbin and Zollinger, in 1930, described osteochondritis of the spine in four members of a family. While osteochondritis of the spine is not anatomically comparable to osteochondritis dissecans of the knee, its presence in four members of the same family certainly suggests that heredity is an etiological factor.

Wagoner and Cohn thoroughly reviewed the literature in 1931 and found several cases occurring in members of the same family. They concluded that there is a hereditary and familial, or congenital, factor which is responsible for the development of osteochondritis dissecans.

In 1934, Rahm reported that in a family of seven children, two brothers had osteochondritis dissecans in the elbow joints, the symptoms having appeared at the age of sixteen years. The same bony changes were noted in the right elbow of four other male relatives (two uncles and two cousins), the symptoms in these patients having appeared at the age of fourteen to sixteen years. Rahm concluded that osteochondritis dissecans is a general constitutional epiphyseal disorder.

In 1933, Müller and Hetzar reported that osteochondritis dissecans of all the large and small joints in association with osteochondritis of the spine was found in a family of two brothers and one sister. The authors were of the opinion that the etiological factor in Schmorl's disease and osteochondritis dissecans is the same, although the symptoms in the latter condition appear after the twelfth year.

FIG. 3-A

Older son, S. D. Roentgenograms of the right knee, made January 24, 1942, when he was ten years old. Note the faint area of lessened density on the medial femoral condyle; this later developed into osteochondritis dissecans. Note also the slight widening of the medial half of the tibial epiphysis.

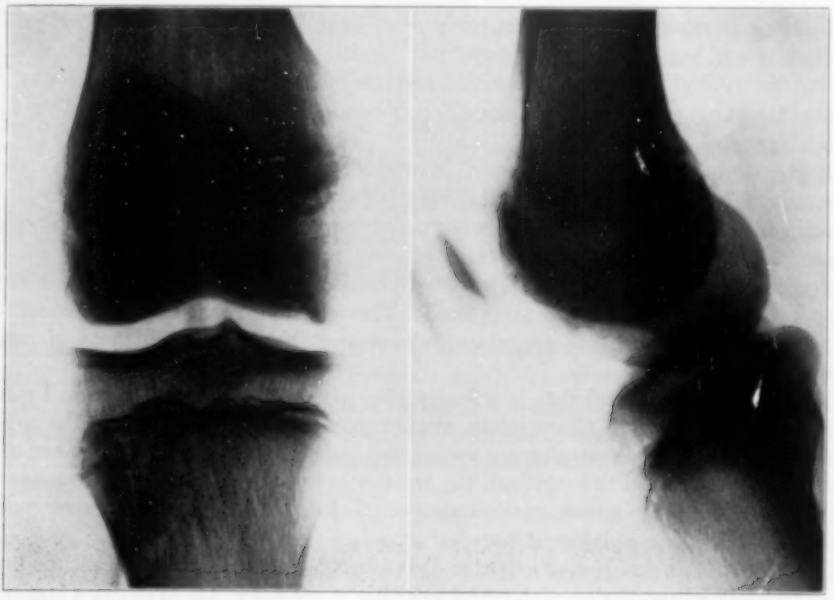

FIG. 3-B

Roentgenograms of the right knee, made July 7, 1947, when he was fifteen years old. Note the well developed osteochondritis dissecans of the medial femoral condyle and the slight widening of the medial half of the upper tibial epiphysis.

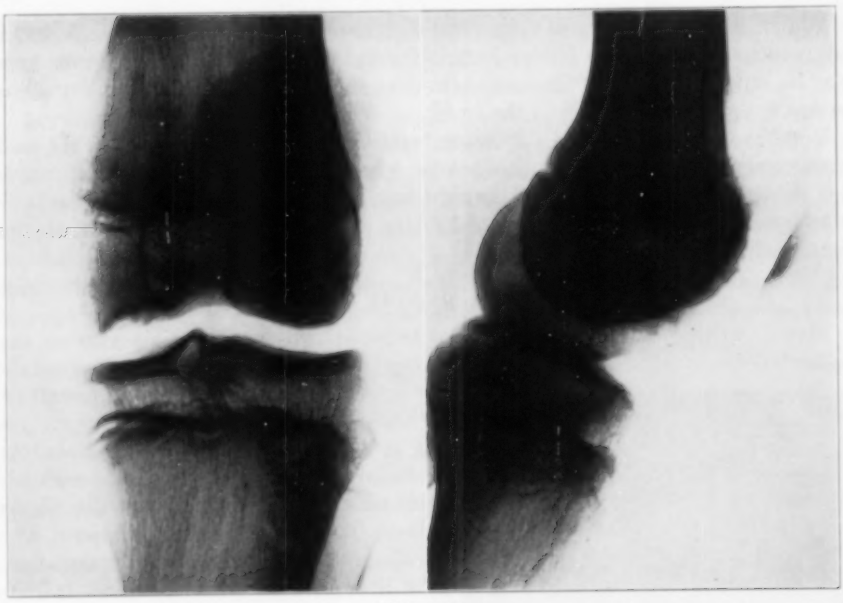

FIG. 3-C

Roentgenograms of the left knee, made July 7, 1947. Note the presence of changes similar to those in the right knee.

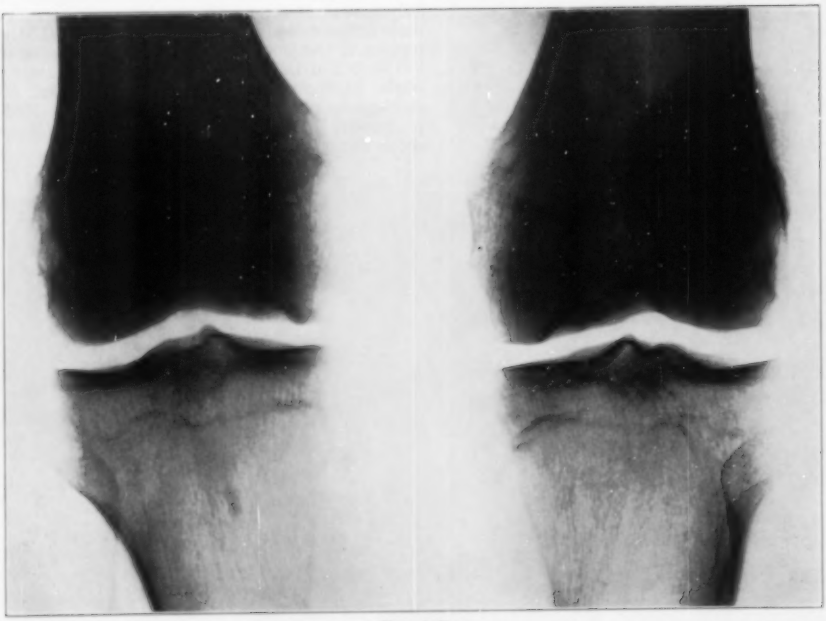

FIG. 3-D

Roentgenograms made November 11, 1951, when he was nineteen. Osteochondritis dissecans is still present; the upper tibial epiphyses have united.

Müller, in a 1939 survey of epiphyseal disturbances in the hip, knee, shoulder, and elbow, concluded that these lesions have a familial origin and that they never appear singly. He reported that all of the patients in the cases studied were short, which may have been due to epiphyseal changes in the spine.

Novotny, in 1952, reported that osteochondritis dissecans was present in the medial femoral condyle of the left limb in one brother when he was eleven and one-half years old and in the lateral femoral condyle of the right limb of another brother when he was twelve. The author concurred with the theory of Ribbing that the condition arises from accessory osseous nuclei of the epiphysis.

TIBIA VARA

Blount, writing in 1937, differentiated between two types of tibia vara or osteochondrosis deformans tibiae: (1) the infantile type, which occurs in children of up to about two years of age, and (2) the adolescent type, which appears in the early adolescent years. It is the adolescent type, associated with familial osteochondritis dissecans, with which this paper is concerned. Blount described the classic roentgenographic appearance as including: (a) a rather abrupt angulation of the tibia just below the proximal epiphysis; (b) a wedged-shaped epiphysis; and (c) a

FIG. 3-E

Fig. 3-E: Roentgenogram of the left knee made May 28, 1954, when he was twenty-two. A loose body is shown lying under the patella.

Fig. 4-A: Younger son, L. D. *Left:* Photograph made July 28, 1947. Note the bowing of the right limb. The left limb appears normal. *Center:* Photograph made July 8, 1948, eleven months after operation on the right limb (arthrotomy and osteotomy through the upper portion of the tibia). Note the definite bowing of the left limb and the valgus deformity of the right limb. *Right:* Photograph made December 31, 1948, sixteen and one-half months after the operation. Note the progressive bowing of the left limb and the valgus deformity of the right limb.

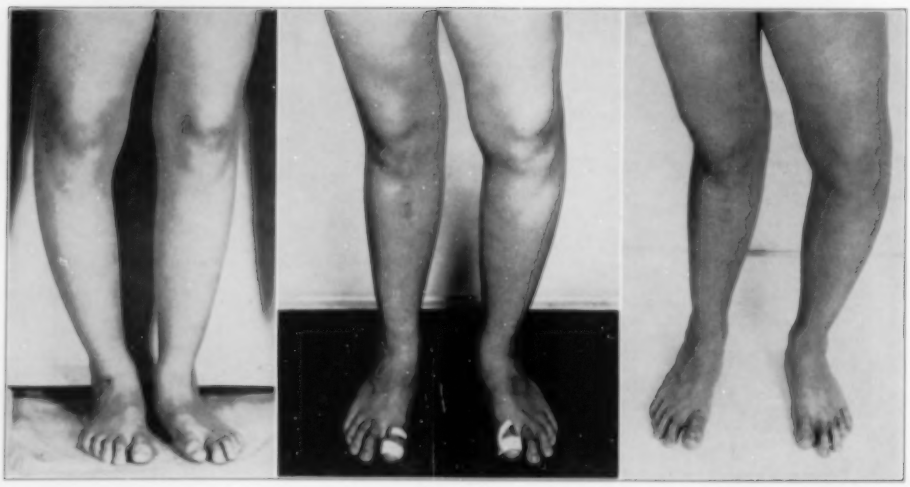

FIG. 4-A

prominent, beaklike, recurving of the medial metaphysis, attributed to arrest of epiphyseal growth. Proper timing of operative intervention is important, as will be illustrated later in this paper. Premature osteotomy may result in recurrence of the deformity.

In 1952, Langenskiöld reported twenty-three cases, seventeen in patients between the ages of one and three and one-half years, and six in patients between the ages of eight and thirteen. In the patients with the infantile type there was an abrupt angulation of the upper end of the tibia. This was sometimes unilateral and sometimes bilateral. At the medial condyle there was a palpable lump, distal to which the diaphysis was straight. Langenskiöld stated that in patients with the adolescent type the deformity is never excessive and is always unilateral. He described the changes which may be seen roentgenographically in the six stages of the deformity. In stage 1, seen at two to three years of age, there is irregular ossification throughout the entire metaphysis. In stages 2 and 3, seen at ages two and one-half to six, the changes are limited to the medial beak-like portion of the metaphysis in which there is a depression filled with cartilage. In stage 4, seen at ages five to ten, the depression in the metaphysis is occupied by the bony epiphysis. In stage 5,

FIG. 4-B

Fig. 4-B: Lateral roentgenogram of the right knee, made July 17, 1947, showing well developed osteochondritis dissecans of the medial femoral condyle.

Fig. 4-C: *Left:* Roentgenogram of the right knee made July 17, 1947. Note the presence of osteochondritis dissecans in the medial femoral condyle, the widening of the medial half of the upper tibial epiphysis, and the angulation at the epiphyseal line. *Right:* Roentgenogram of the left knee, made July 17, 1947. There is no evidence of osteochondritis dissecans and no angulation of the tibia.

FIG. 4-C

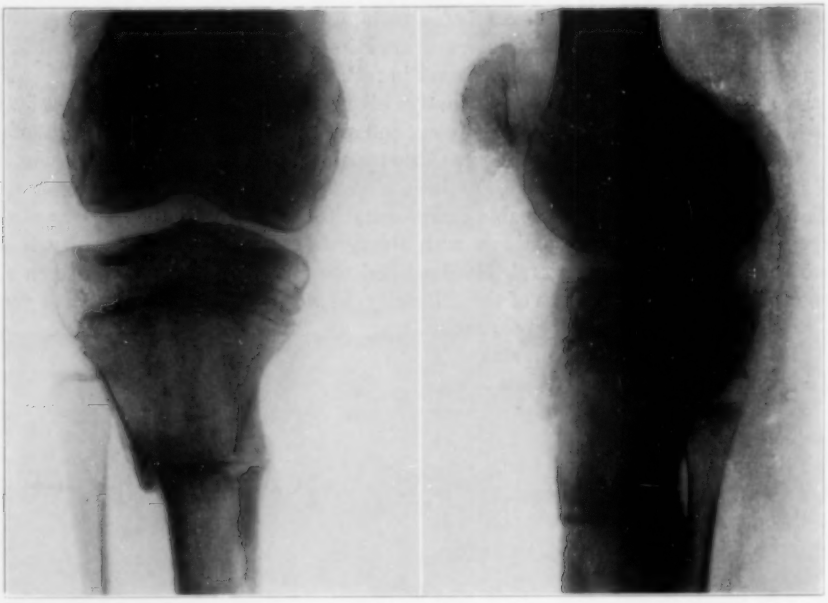

FIG. 4-D

Roentgenograms made two months after operation on the right knee (arthrotomy, excision of the area of osteochondritis dissecans, and osteotomy of the upper portion of the tibia, with insertion of a bone graft obtained from the adjacent portion of the tibia).

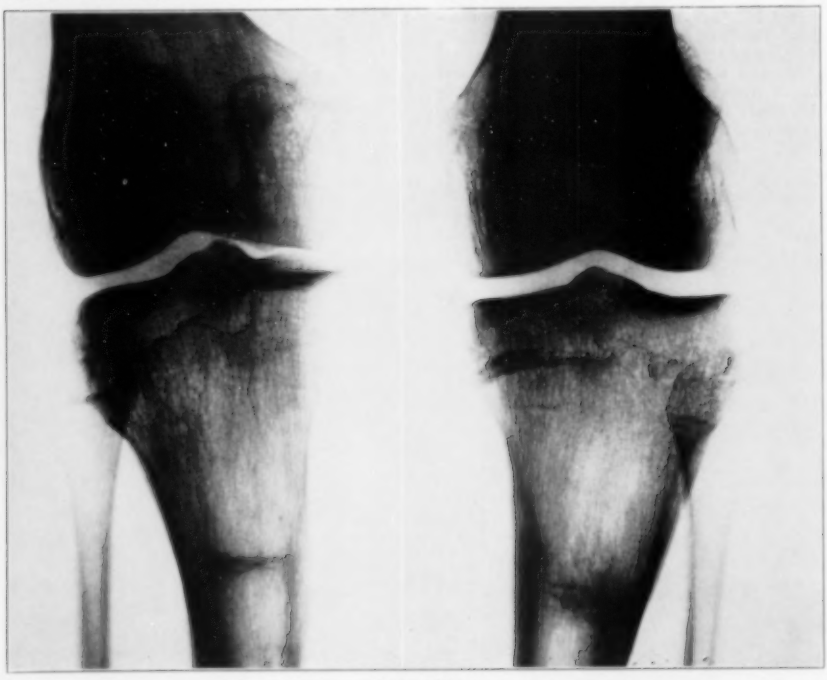

FIG. 4-E

Roentgenograms made May 28, 1950, four and one-half months following osteotomy of the left tibia. *Left:* In the right limb, the upper tibial epiphysis has united. The valgus deformity is still present. *Right:* In the left limb the medial half of the upper tibial epiphysis has not completely united. A moderate varus deformity is still present.

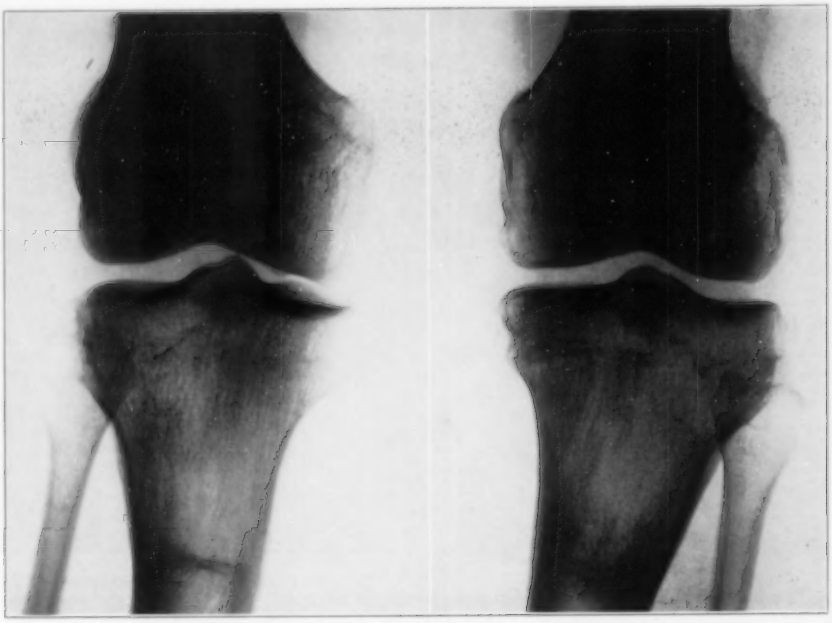

FIG. 4-F

Roentgenograms made November 18, 1951, when he was sixteen years old. The upper tibial epiphyses have united. The defect in the right medial femoral condyle has filled in.

FIG. 5

Photograph made November 8, 1951. *Left:* the older son, S. D., at nineteen years of age; he received no treatment. *Center:* the younger son, L. D.; there was improvement in the bowing of the left limb but persistence of the valgus deformity of the right limb. *Right:* the daughter, R. D., who still had no bowing.

ages nine to eleven, the medial part of the epiphysis forms an irregularly bordered triangular fragment between two layers of "partially-double epiphyseal plate." In stage 6, the medial part of the epiphyseal plate is ossified.

Histological findings suggest a disturbance in the growth, maturation, and ossification

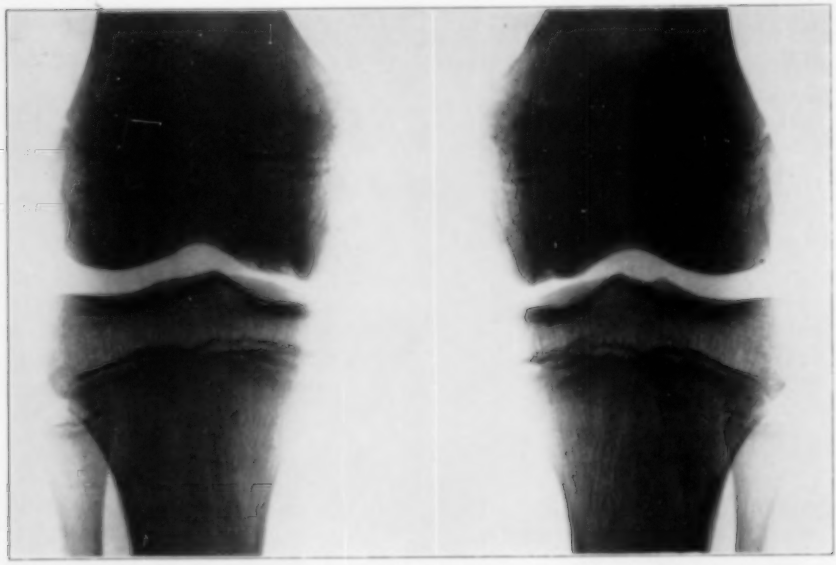

FIG. 6-A

The daughter, R. D. Anteroposterior roentgenograms, made July 22, 1947, when she was eleven years old. Osteochondritis dissecans is present in both knees.

FIG. 6-B

Lateral roentgenograms, made July 22, 1947, showing osteochondritis dissecans of both medial femoral condyles.

of the epiphyseal cartilage as an essential factor. Langenskiöld suggested that early osteotomy without marked overcorrection is the treatment of choice for a varus deformity of over 10 degrees. He stated that in patients over nine years of age recurrence may follow.

TREATMENT

While this paper is not primarily concerned with the various methods of treatment of osteochondritis dissecans and osteochondrosis deformans tibiae, it is desirable to at least mention that in children, conservative supportive non-operative measures are both effective and desirable.

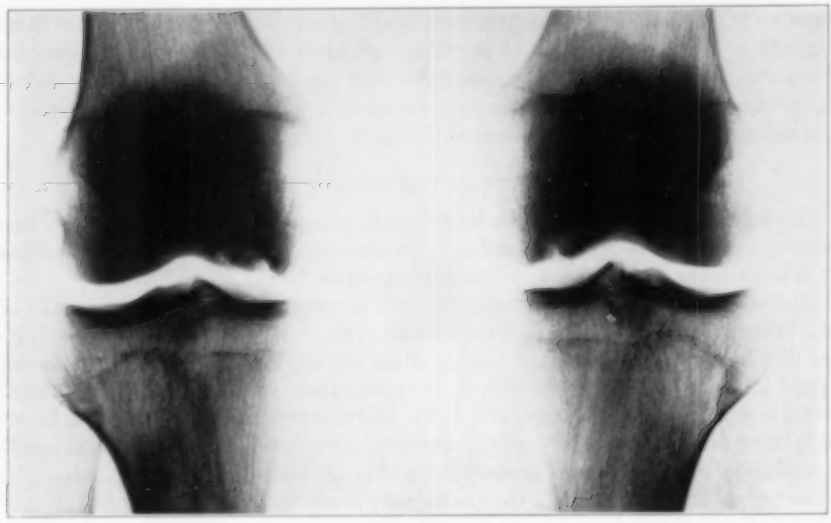

FIG. 6-C

Roentgenograms made May 28, 1950, showing partial healing of the osteochondritis dissecans. There is no bowing of the limb.

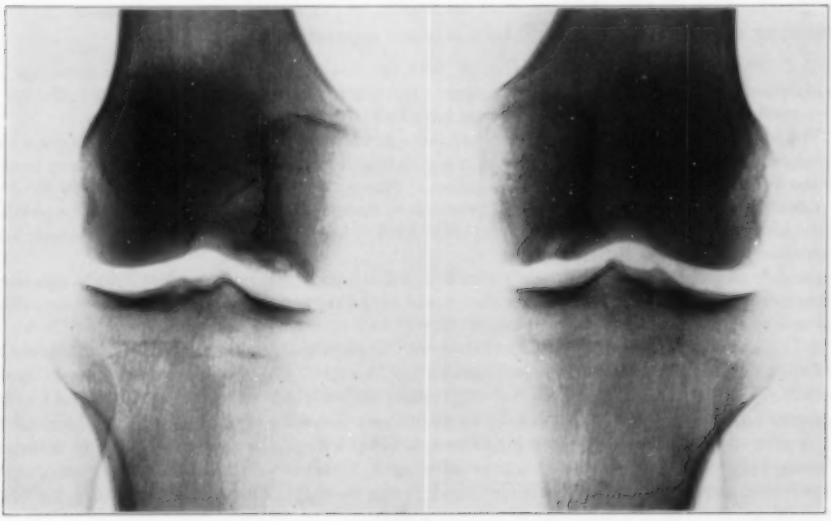

FIG. 6-D

Roentgenograms made when the patient was fifteen. Note that there has been further healing of the osteochondritis dissecans and that the upper tibial epiphyses have united. She had no complaints. Bowing did not develop, as it did in her father and brothers.

In Green and Banks' series of cases of osteochondritis dissecans reported in 1953, there were thirty-six involved joints (thirty-two knees) in twenty-seven children under sixteen years of age. Twenty-five of the joints were treated by a Thomas patten-bottom brace or by a flexion cast. The authors stated that trauma is the major causative factor of this condition but admitted that there may be an underlying factor which makes certain individuals particularly susceptible.

With regard to osteochondrosis deformans tibiae or tibia vara, the treatment is supportive and symptomatic, being directed toward the relief of strain until epiphyseal

maturation is reached. Unilateral epiphyseal stapling is a worth-while procedure to retard the growth of the lateral portion of the tibial epiphysis and thus to prevent progression of the varus deformity. Premature osteotomy will result in recurrence of the deformity or, if varus deformity develops in the opposite knee, it will result in the development of a valgus deformity, as illustrated in one of the cases discussed later in the paper.

CLINICAL CASES

The author's series, while numerically small, presents strong evidence that there is a common etiological factor in osteochondritis dissecans and tibia vara of the adolescent type. The patients described are members of the same family.

Clinical and roentgenographic studies of the mother revealed no abnormalities of the knees. When the father, H. D., aged sixty-one years, was seen on July 12, 1947, it was found that he had a well developed bowing of the left leg, and a slight valgus deformity of the right knee (Fig. 1). The older son, S. D., aged fifteen years at that time, had definite bilateral bowing, while the younger son, L. D., had a severe bowing of the right limb, this bowing being of the angulation type with the apex at the level of the upper tibial epiphysis. The findings of the examination of the left leg of L. D. were within normal limits. Clinical examination of the daughter, R. D., aged eleven years, revealed no abnormalities of the knees. In all members of the family, the second toes were unusually long, and relaxation of the collateral ligaments was noted in the father and both sons, all of whom had varying degrees of tibia vara. The entire family was short, averaging five feet, two inches when full grown. Two of the children had unusually short fourth fingers. Because of certain interesting aspects, each case will be discussed separately.

H. D. The father was examined on July 28, 1947, because of pain in his left knee. At about age twelve he had noticed bowing of the left leg below the knee, and prior to this he had experienced pain in the left knee. He reported that the paternal grandfather may have had bowing of the knees.

The patient walked with a definite limp and there was bowing or angulation of the left lower extremity just below the knee. There was instability of the collateral ligaments of the left knee, localized tenderness over the medial aspect of this knee, and 10 degrees of flexion deformity, with further flexion to 105 degrees.

Roentgenograms revealed moderate degenerative changes on the under surfaces of the patella and femoral condyles, narrowing of the medial aspect of the left knee, and the presence of a loose body lying in the anterior compartment of the knee (Fig. 2).

On July 30, 1947, arthrotomy was performed, a loose body measuring approximately three by two centimeters being removed. The postoperative course of the patient was uneventful, and he was clinically improved by the removal of the loose body.

J. D. The mother had no complaints and there were no abnormal physical findings referable to her knees. The findings of the roentgenograms were within normal limits.

S. D. The older son first complained of vague pains in the right knee in 1942, when he was ten. Roentgenograms made at that time revealed a faint area of lessened density on the medial femoral condyle which later developed into definite osteochondritis dissecans (Fig. 3-A). There was slight widening of the medial half of the upper tibial epiphysis. At that time there was no apparent bowing of the lower extremities. At age twelve progressive bowing of both limbs developed first on the right and then on the left (Fig. 1). Examination of the knees revealed a full range of painless motion.

Roentgenograms made July 7, 1947, five and one-half years later, showed well developed osteochondritis dissecans of the medial femoral condyles and widening of the medial half of the upper tibial epiphysis bilaterally (Figs. 3-B and 3-C). Lateral roentgenograms revealed defects in the medial femoral condyles but no loose bodies in the knee joints. Roentgenograms made June 20, 1950, when the patient was eighteen and one-half, revealed that the osteochondritis was still present but that the area involved was smaller than in 1947. The upper tibial epiphyses had united. Roentgenograms made November 8, 1951, revealed no appreciable change in the appearance of the osteochondritis dissecans (Fig. 3-D). On May 28, 1954, the patient complained of intermittent locking, swelling, instability, and pain in the left knee. Roentgenograms revealed a definite loose body lying in the anterior compartment of the knee (Fig. 3-E).

Although the slight area of lessened density found on the medial femoral condyle in 1942 was interpreted as normal at the time, it is now felt that it was the early stage of osteochondritis dissecans. This area was subsequently sequestrated into the knee joint as a loose body. The patient received no treatment at any time for either the osteochondritis dissecans or the adolescent tibia vara. The osteochondritis dissecans apparently preceded the development of tibia vara.

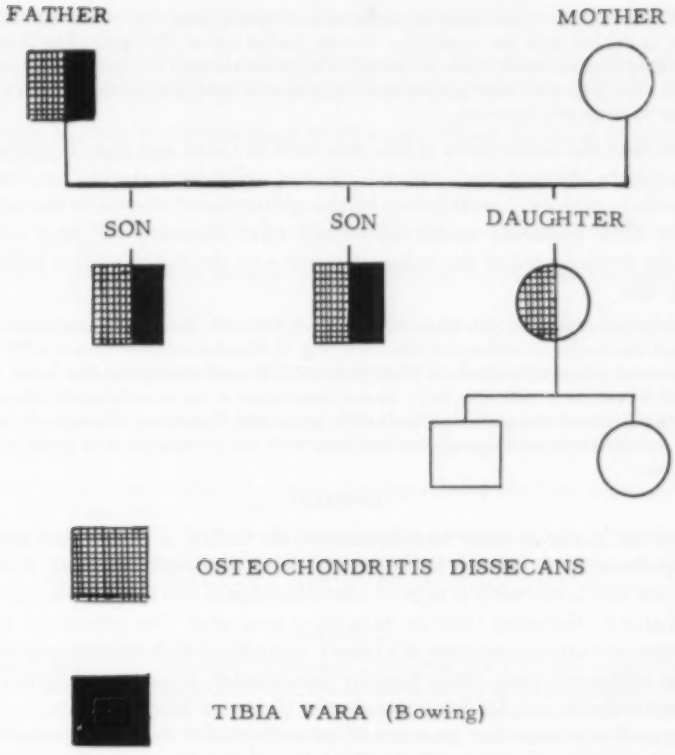

CHART I

Chart showing distribution of osteochondritis dissecans and tibia vara. The tibia vara is a sex-linked characteristic, being seen in the father and the two sons. The mother showed neither osteochondritis dissecans nor tibia vara, and the daughter showed only osteochondritis dissecans.

L. D. By July 28, 1947, the younger son had definite tibia vara of the right leg, characterized by angulation at the upper tibial epiphysis. His chief complaint was pain in the right knee of six months' duration, associated with disability in certain movements such as running and squatting. There was definite relaxation of the medial collateral ligament and localized tenderness over the medial femoral condyle (Fig. 4-A, *left*).

Roentgenograms made July 28, 1947, revealed osteochondritis dissecans of the medial femoral condyle of the right knee, with widening of the medial half of the upper tibial epiphysis and angulation of the tibia at this site (Fig. 4-B). There was a suggestion of an area of lessened density in the left medial femoral condyle, but there was no widening of the medial portion of the upper tibial epiphysis. Lateral roentgenograms of the right knee showed an area of lessened density on the medial femoral condyle (Fig. 4-C). Clinically, the left knee at this time presented a normal appearance and the roentgenographic findings were within normal limits.

At operation on August 11, 1947, arthrotomy of the right knee was done with removal of the area of osteochondritis dissecans. The area of the osteochondritis dissecans was found to be covered with a dull, yellowish layer of cartilage but had not separated. Through a separate incision made approximately two inches below the level of the knee joint, a wedge osteotomy of the tibia was performed, a bone graft from the adjacent portion of the tibia being inserted for reinforcement. Roentgenograms made two months after the osteotomy revealed that the tibia vara had been corrected and that the osteotomy cut had healed satisfactorily (Fig. 4-D). Nine months after the operation bowing of the left leg developed. Photographs made eleven months after the operation showed progressive bowing of the left leg and beginning valgus deformity of the right leg (Fig. 4-A, *center*).

Roentgenograms made December 28, 1948, sixteen and one-half months after the operation, revealed the osteotomy cut in the right tibia to have completely healed. There was progressive marked valgus deformity in the right knee and varus deformity in the left knee (Fig. 4-A, *right*). On January 6, 1950, an osteotomy of the upper portion of the left tibia was performed in order to correct the varus deformity. Roentgenograms made May 28, 1950, revealed the osteochondritic defect in the right knee to have been

completely filled in and the upper tibial epiphysis to have united (Fig. 4-E). They also showed that the osteotomy cut in the left tibia had healed but that the medial half of the upper tibial epiphysis still had not united. Roentgenograms made when the patient was sixteen revealed the upper tibial epiphyses to have united on both sides (Fig. 4-F). Photographs made November 8, 1951 (Fig. 5), showed the varus deformity of the left knee to be greatly improved.

It is felt that the osteotomies in this case were ill timed and that if osteotomy is to be done, it should be delayed until full growth and epiphyseal closure has been attained. Local controlled epiphyseal retardation by the utilization of staples in the lateral portion of the upper tibial epiphysis would most likely have corrected the tibia vara and have prevented the development of the valgus deformity on the right as varus deformity developed on the left.

R. D. The daughter was first seen when she was eleven years old. She had no complaints referable to her knees and there was no clinical evidence of tibia vara (Fig. 1). Roentgenograms made July 22, 1947, revealed typical bilateral osteochondritis dissecans (Figs. 6-A and 6-B) and roentgenograms made May 28, 1950 (Fig. 6-C), and November 8, 1951 (Fig. 6-D), showed persistence of the osteochondritis dissecans but no retardation in the closure of the medial portion of the upper tibial epiphyses. Photographs made when she was fourteen and fifteen years of age showed that tibia vara did not develop as it did in her two brothers and in her father.

SUMMARY

An attempt has been made to substantiate the feeling of others that osteochondritis dissecans, perhaps more appropriately termed *osteochondrosis dissecans*, is not a clinical entity in itself but is probably a type of osteochondrosis, the etiology of which is not understood. Various etiological theories have been proposed. The occurrence of osteochondritis dissecans in various members of a family, associated with osteochondrosis deformans tibiae of the adolescent type, while possibly coincidental, is most suggestive of some common etiological factor and further supports the theory of heredity.

In the author's cases the presence of osteochondritis dissecans probably preceded, from a chronological viewpoint, the development of tibial bowing. From a genetic viewpoint, it is interesting that the mother of the patients showed neither osteochondritis dissecans nor bowing. The father and two sons illustrate the coexistence of osteochondritis dissecans and adolescent tibia vara, whereas the daughter demonstrated the presence of osteochondritis dissecans without adolescent tibia vara (Chart I).

The paper is not intended to propose any new theories regarding etiology or to discuss treatment in detail. The ill timing of osteotomy is clearly demonstrated. If the deformity is sufficiently severe to warrant osteotomy, this procedure should be postponed until bone maturity is reached; otherwise recurrence of the deformity is likely. Controlled epiphyseal retardation by the use of staples in the lateral portion of the upper tibial epiphysis is recommended as a more conservative form of operative treatment.

Note: The author is indebted to Dr. Aaron Nimetz for having referred the above cases for evaluation and follow-up.

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DISCUSSION

Dr. Donald E. King, San Francisco, California: During the past few years a number of interesting papers have been written concerning multiple osteochondroses occurring in the same patient. A few of these papers have described cases in which there was a hereditary or familial tendency for this condition.

Not all tibia vara deformities require osteotomy, for in some cases spontaneous correction of the deformity occurs. In other cases, however, a slow progressive increase in the deformity necessitates osteotomy. Just how severe the deformity should be before operation is considered and at what age the operation should be done are questions to which there are no completely satisfactory answers. If the deformity is mild and the knee remains fairly stable, operation can be postponed until the epiphyses have closed. On the other hand, if there is a progressing deformity in a very young child osteotomy should be done early with the idea of repeating the operation later if the deformity recurs. There is no satisfactory explanation for the occurrence of these deformities.

With regard to osteochondritis dissecans, Smillie records the case of a young man who, following a blow on the outer side of the knee, was operated upon for a torn medial meniscus. At operation the meniscus was found to be perfectly normal, but it was quite obvious that the medial spine of the tibia had been thrust against the articular cartilage of the medial femoral condyle, fracturing off a piece of it; this piece was exactly the same in shape and anatomical location as the loose body found in the typical case of osteochondritis dissecans. We have seen four cases of osteochondritis dissecans of the talus following trauma, two following sprain, and two following fracture of the fibular malleolus. One patient, a boy of eighteen, fractured his fibular malleolus while skiing. The fracture healed well, but four years later he returned with osteochondritis dissecans of the talus.

Dr. Brandon Carroll, Dallas, Texas: Dr. Tobin has given us an interesting and thought-provoking paper. Personally, I have not encountered this exact combination of abnormalities.

Certainly there is very little question as to the familial or hereditary factor in this particular group of cases; the changes described definitely appear to be manifestations of a generalized hereditary epiphyseal disturbance. Whether all cases of osteochondritis dissecans and all cases of tibia vara are manifestations of the osteochondroses and are hereditary, however, is questionable. If so, we should find a familial tendency in a much higher percentage of patients than at least I have. In this group and in some of the other relatively rare cases of osteochondritis in members of the same family, it can be noted that there is a tendency to shortness of stature. This is suggestive of a generalized epiphyseal disturbance, and my feeling is that these families are particularly susceptible to such pathological changes, just as other short-statured families show definite tendencies to congenital genu varum or other abnormalities.

I agree with Dr. Tobin's recommendations as to treatment except that I prefer the use of plaster fixation in the early treatment of osteochondritis dissecans. It might have been interesting to see the possible effect of this treatment had it been tried on one of the two boys when the osteochondritis first became evident.

Integrated Actions and Functions of the Chief Flexors of the Elbow

A Detailed Electromyographic Analysis *

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Although they can be felt quite easily, the biceps brachii, the brachialis, and the brachioradialis have not been fully understood as far as their integrated functions are concerned. Although it is obvious that these muscles are primarily concerned with flexion, a variety of theories have obscured the role played by each during flexion and other movements of the elbow. It is probably fair to say that the few formal studies of these muscles, both with and without objective techniques, have been either too sharply circumscribed in approach or too highly generalized and semideductive. For these reasons, we have made a detailed electromyographic study of both heads of the biceps, the brachialis, and the brachioradialis. The findings of the present study promise to be useful in broadening our understanding of the function of skeletal muscles in general.

MATERIAL AND METHODS

The subjects of the study were twenty normal young adults, all medical students or physical therapists. Twelve were male and eight were female. The arm used for study in each case was chosen in a random fashion.

Apparatus

A six-channel Stanley Cox electromyograph equipped with audio and visual units was used for the study.

The electromyograph consists of six identical separate amplifiers situated in the top of a single cabinet together with a control unit. In the bottom of the cabinet is the power-supply unit and a light-proof compartment containing a row of seven small cathode-ray tubes, six for the six input channels or amplifiers and one for a time marker. The time is marked at 100 oscillations per second. (In Figure 1, each vertical time-mark indicates 0.01 second.) The cathode-ray tubes face a Cossar linagraph camera which records the seven parallel tracings on thirty-five millimeter moving film. At the back of the cabinet is a loudspeaker which can be switched from channel to channel. On the upper surface of the cabinet there are visible the faces of six small cathode-ray tubes for continual monitoring. Recordings are made by flipping a single switch which starts the motor that moves the film and also brightens the beams of the recording oscilloscopes. The frequency response of the apparatus is 10 to 5000 cycles per second.

Electrodes

Bipolar concentric-needle electrodes (of a type which limit their pick-up to a volume of about one cubic inch) were used throughout. The surface of the skin was anaesthetized by raising small wheals with 1 per cent procaine at the sites selected for insertion of the electrodes. The electrodes were then thrust into the muscles, one into each head of the biceps, one into the brachialis from its lateral side, and one into the brachioradialis. An effort was made to place the tip of the electrode in the middle of the muscle belly. (We have demonstrated in other experiments that all parts of a muscle belly, even of a long

* Parts of this work were included in a thesis for the M.A. degree granted to Mr. Latif (Colombo Plan Fellow from Karachi, Pakistan) by the University of Toronto in 1956. The work was supported in part by a grant from the Colombo Plan and in part by the Bickell Foundation, Toronto.

muscle such as the rectus femoris, show relatively similar activity, the greatest activity occurring in the middle of the belly.)

The needles did not appear to interfere with movements in any instance. When pain was a factor, however, care was taken to replace the needles in more comfortable positions. With few exceptions, the positions of the needles were kept relatively constant during the course of the experiment.

The subject was grounded by a wire running to a silver earring electrode.

Experimental Procedure

During studies of flexion, extension, maintenance of elbow flexion at 135 degrees, and pronation and supination of the forearm, each subject was lying supine on a padded table. During studies of maintenance of elbow flexion at 90 degrees, the subject was sitting erect; and during flexion and abduction of the shoulder, the subject was standing erect.

Permanent photographic records of every observation were made, one after another, on 100-foot lengths of thirty-five millimeter film. Because the recordings were obtained from the four electrodes simultaneously and because relatively painless needle electrodes, cathode-ray oscilloscopes, and photographic recording were used throughout, we feel confident that, for the first time, the results are a true picture of the activity in these muscles.

In each instance, the subject was briefly instructed as to the movement or position desired. The camera was started shortly before the beginning of the movement and was stopped shortly after the movement was completed. Thus a baseline of inactivity before and after movement was provided. The subjects were not trained, but each made the movements in his own usual way. Both before and after each record of movement or position, separate records were also made with the arm and forearm relaxed and supported on the table.

All movements and positions were studied with no resistance and with a load (an iron weight) of two pounds held loosely in the hand. Additional studies were made in which the moderate (but obviously not wholly controlled) resistance of an observer's handgrip was used during the pronation-supination experiments.

Interpretation of the Records

The developed films were studied through a magnifying viewer. From past experience in this department and from the experience of others, it was possible to delineate with considerable ease nine degrees or grades of activity, as well as no activity. For purposes of tabulation, the figures 0, ½, 1, 1½, 2, 2½, 3, 3½, 4, and 5 were used to denote the increasing degrees of activity.

For the purpose of description, these degrees of activity were also grouped into five general types: no activity, slight activity (½ to 1), moderate activity (1½ to 2), marked activity (2½ to 3½), and very marked activity (4 to 5). In some cases in which the arithmetic mean was between ½ and 0, two extra terms *very slight* and *negligible* have been used in description. The percentage frequency of these types of activity was calculated for each of the four muscles (considering, in this instance, each head of the biceps as a separate muscle) during the movements and positions under consideration.

Finally, it may be noted that, in determining general trends of activity, there was a remarkable agreement between the arithmetic mean of the numerical data and the impression given by the percentage-frequency tables.

FINDINGS

The details of the incidence of various grades of activity in the three muscles during the various movements and postures are presented in Charts I to V. (The results for maintenance of flexion at an elbow angle of 90 degrees while the subject was erect are not shown

but were very similar to those for maintenance at 135 degrees with the subject lying supine.)

Sequence of Appearance and Disappearance of Activity

Detailed tabulation and consideration of the order in which the muscles began to act and stopped yielded several general findings.

There appears to be a completely random selection in the sequence of appearance and disappearance of activity in these muscles. For example, during slow flexion with the fore-

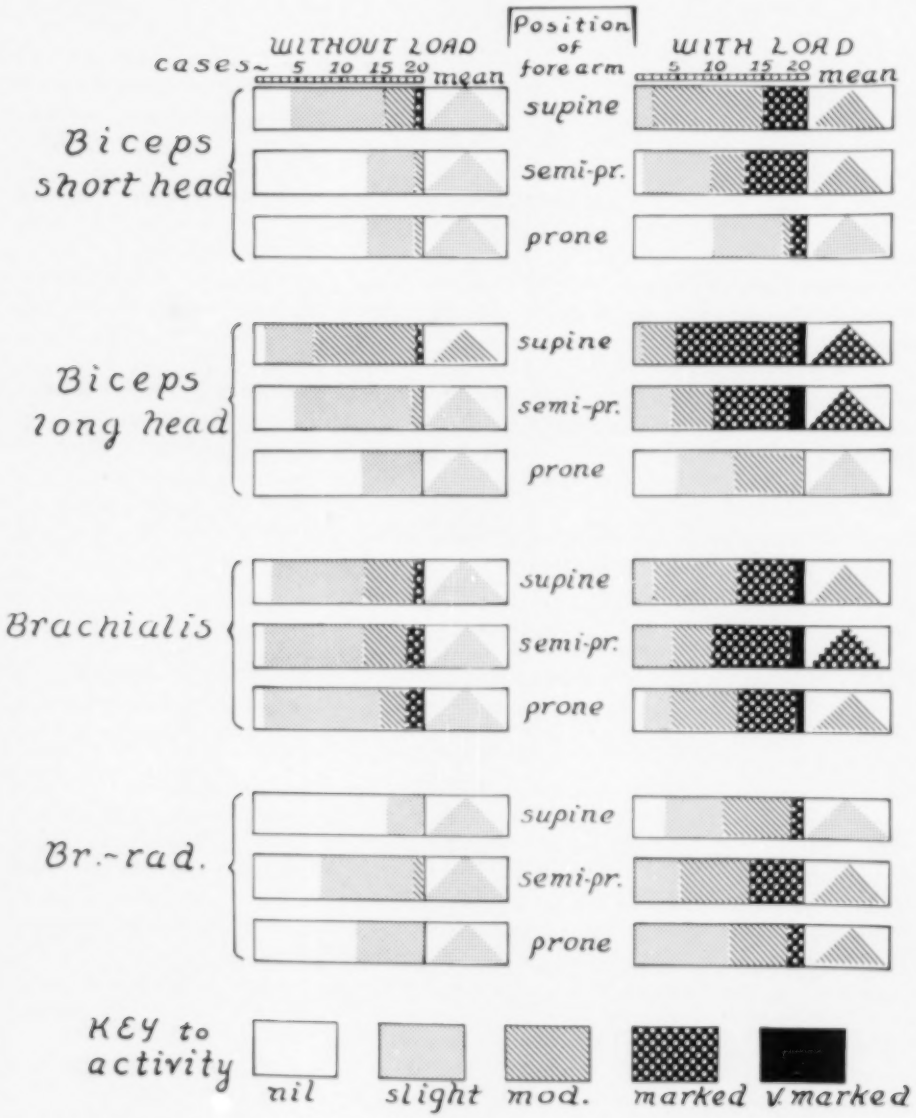

CHART I

Slow flexion of elbow. Composite graph shows the incidence of types of electromyographic activity in the flexors under various circumstances.

arm supine, all the muscles that showed any activity began this activity simultaneously in nine subjects out of nineteen. However, in only four of these subjects did the activity end simultaneously. In four subjects in whom the activity in the muscles did not begin simultaneously, it ended simultaneously.

Any of the four muscles that were to show activity during a movement functioned first or last in an unpredictable fashion. There was no set pattern. In the same way, the activity ceased in the muscles in an unpredictable order. Moreover, the muscle that was to show the greatest activity in individual subjects only occasionally began first and ended last (Fig. 1).

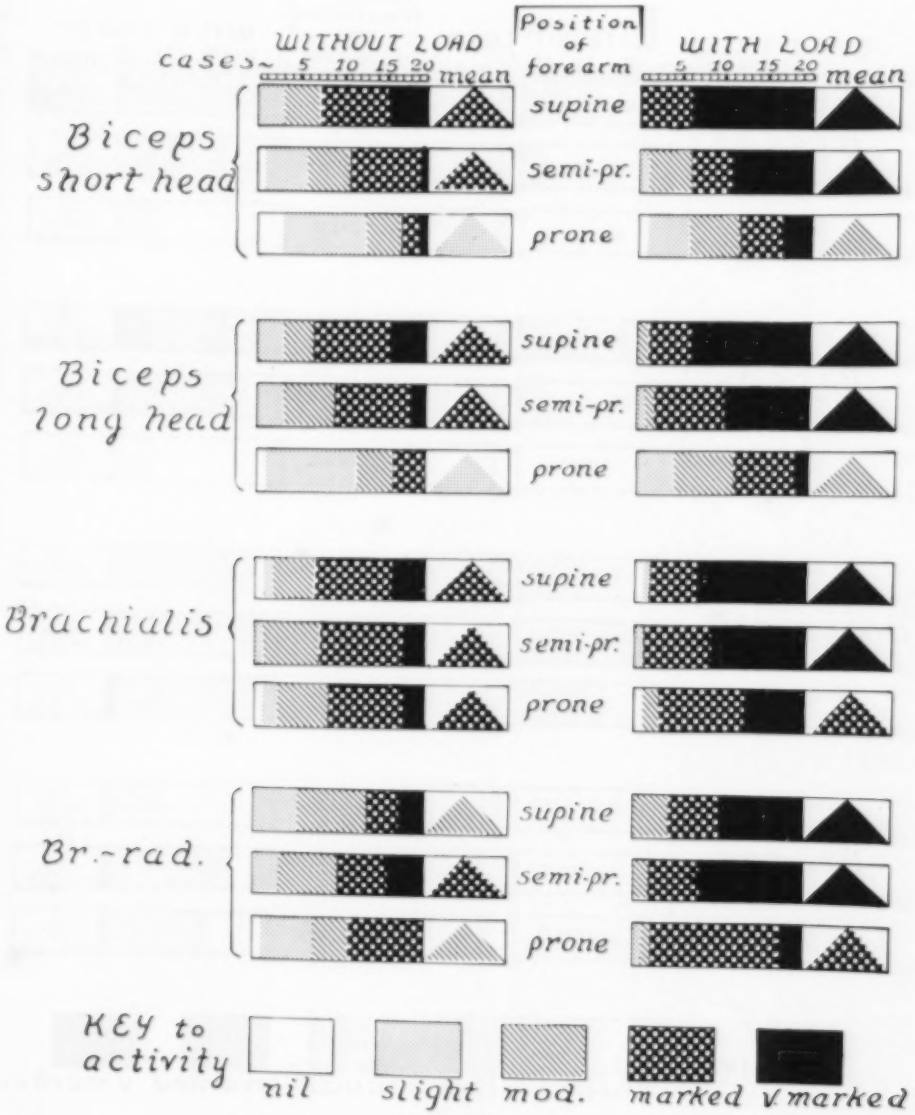

CHART II

Quick flexion of elbow. Composite graph shows the incidence of types of electromyographic activity in the flexors under various circumstances.

Supination of Forearm

During supination of the forearm with the elbow fully extended, no action potentials were recorded from these muscles in the majority of the subjects (in 75 per cent of the short heads of the biceps and in 60 per cent of the long heads of the biceps).

When supination was resisted by the firm grip of the observer, marked activity appeared in the two heads of the biceps. The brachialis and the brachioradialis also showed some potentials. The activity in the brachialis was probably caused by reflex flexion of the forearm which is almost inevitable during supination against resistance.

In three subjects, there was marked activity in the biceps while there was no activity

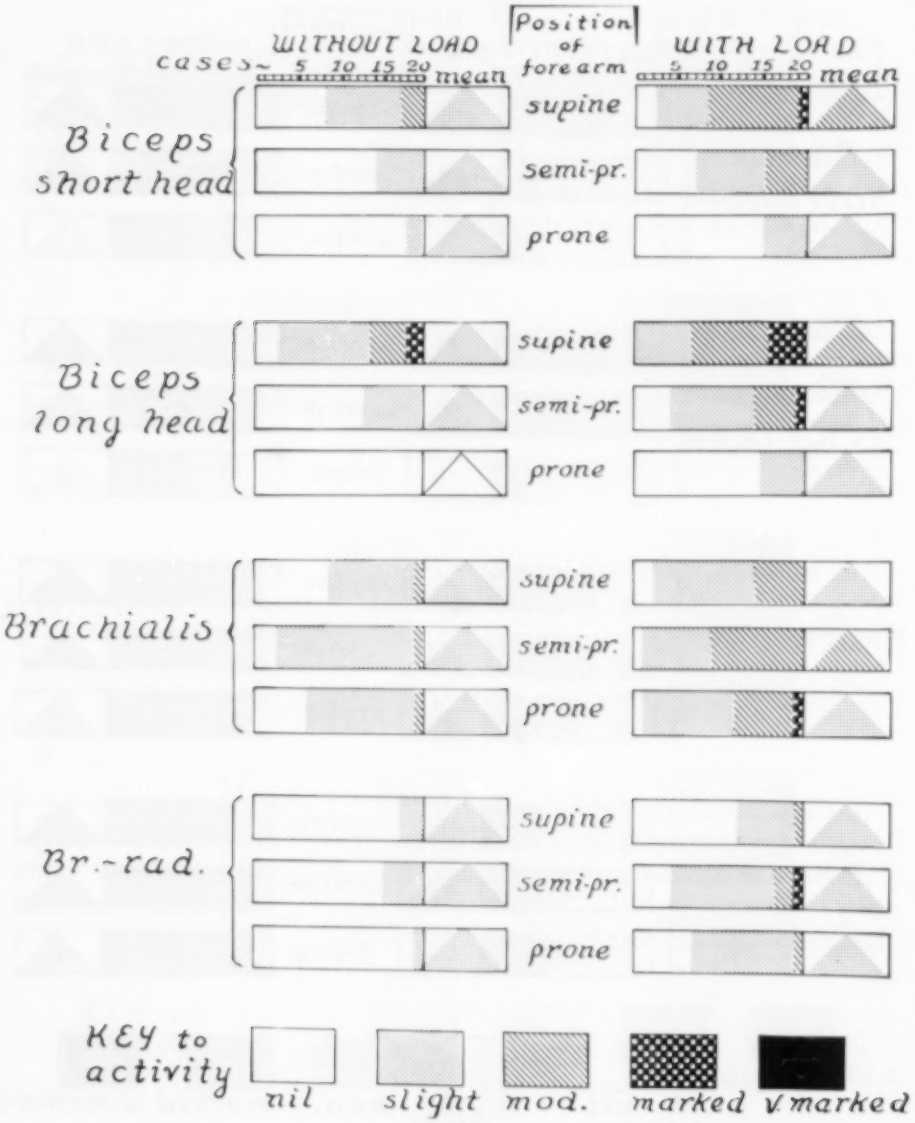

CHART III

Maintenance of elbow flexion at 135 degrees (subject lying supine). Composite graph shows the incidence of types of electromyographic activity in the flexors under various circumstances.

in the brachialis. In one of these subjects, the brachioradialis also showed activity. In all subjects, however, there was activity in the biceps during supination of the forearm against resistance.

Pronation of Forearm

No activity was shown by any one of the muscles during pronation with the elbow fully extended. When this was tried against resistance offered by the observer, potentials of marked amplitude were recorded from the brachioradialis. Slight activity was seen in the other two muscles. This was perhaps caused by the slight flexion that occurs when the forearm is pronated against resistance.

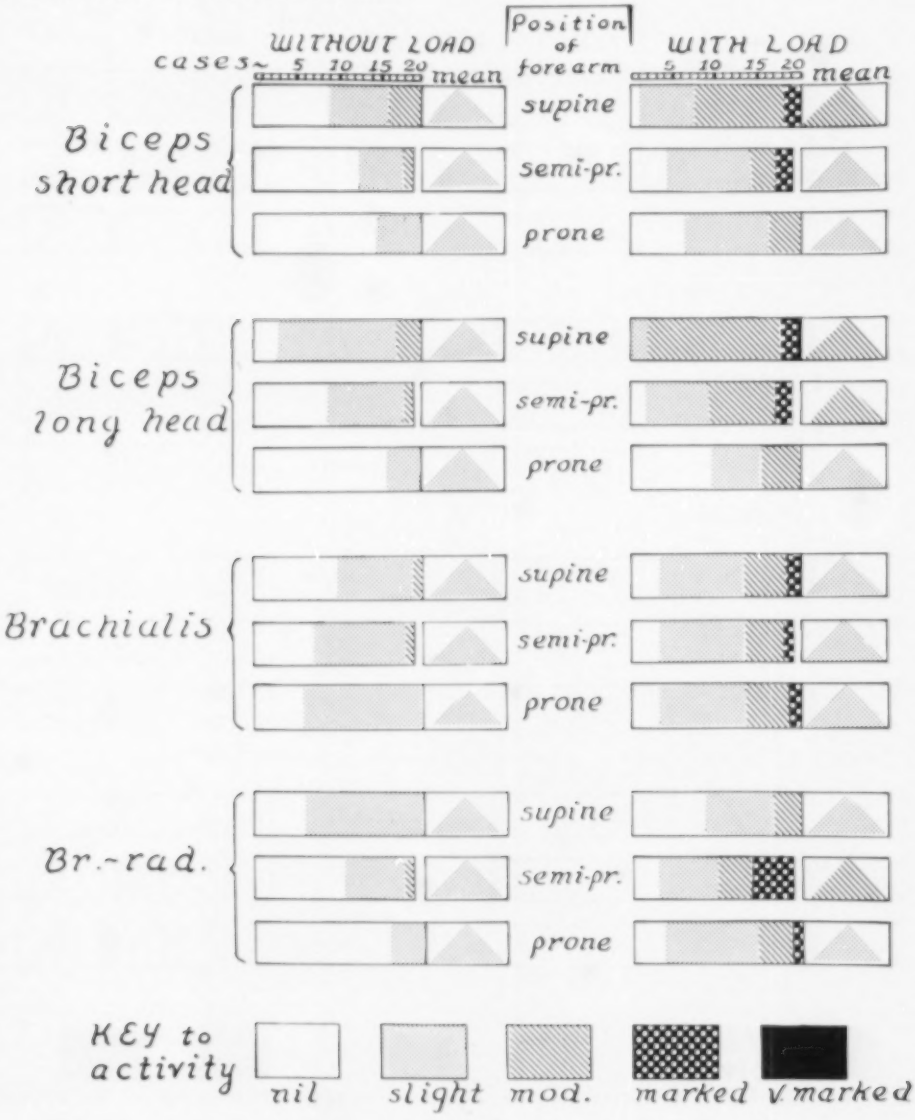

CHART IV

Slow extension of elbow. Composite graph shows the incidence of types of electromyographic activity in the flexors under various circumstances.

Flexion of Shoulder Joint

Action of the biceps muscle was studied during flexion of the shoulder joint in eleven subjects with the forearm in supination; in seven the forearm was semiprone. In both of these positions of the forearm during flexion of the shoulder, activity was observed in the two heads of the biceps. The long head of the biceps was relatively more active.

Maintenance of Abduction of Arm

With the subjects standing erect, the arm was maintained in abduction at a right angle with the trunk. This position of the arm was studied with the forearm supine in

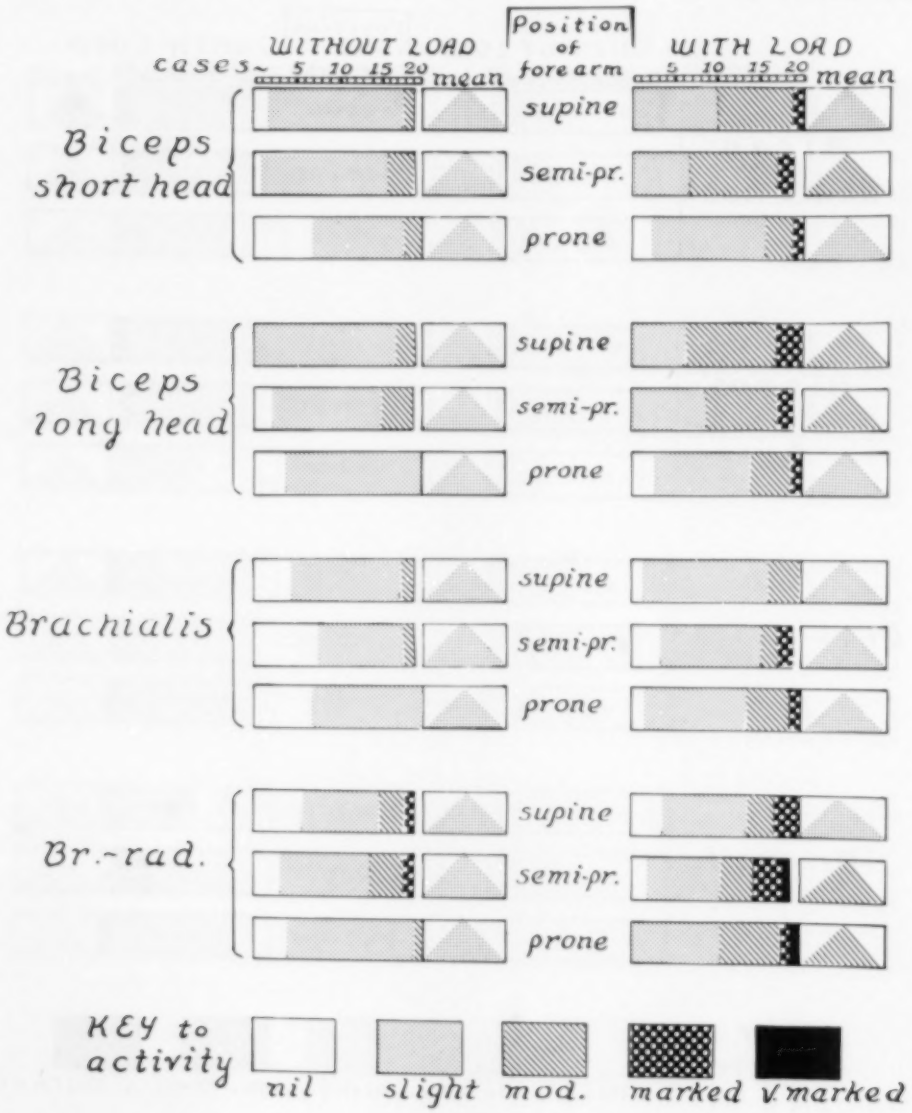

CHART V

Quick extension of elbow. Composite graph shows the incidence of types of electromyographic activity in the flexors under various circumstances.

eleven subjects and with the forearm prone in six. There is, unfortunately, a marked element of lateral rotation of the humerus inseparable from complete supination of the forearm when the arm is abducted. In the subjects with the forearm supine and the humerus rotated laterally, activity was noticed in both heads of the biceps, more in the long head than in the short head. However, in two subjects no activity was recorded in this muscle. In none of the subjects with the forearm pronated and the humerus rotated laterally were action potentials demonstrated in the biceps.

Relaxation

The patterns recorded during the resting position before and after the various studies invariably showed complete absence of activity in all the muscles regardless of whether the forearm lay supine, semiprone, or prone upon the table.

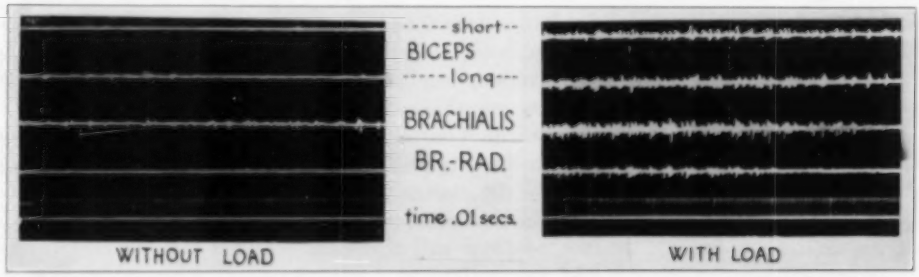

FIG. 1

Sample electromyogram of elbow flexors during slow flexion with the forearm semiprone.

ANALYSIS OF INDIVIDUAL MUSCLES

Biceps Brachii

1. *Short Head of Biceps*

When flexion was performed slowly and without a load, the short head of the biceps acted only when the forearm was in the supine position. When the movement was done with a load of two pounds, this muscle took part in flexion of the semiprone forearm. With the forearm prone, flexion was performed only very slightly by this muscle even when a weight of two pounds was lifted during the movement.

In quick flexion, the activity in the muscle appeared as a short burst. The degree of activity varied, generally being marked in the supine position, moderate in the semiprone position, and only slight in the prone position of the forearm.

During isometric contraction with the elbow held flexed at an angle of either 90 degrees or 135 degrees and without added load, there was slight activity in the short head of the biceps only when the forearm was supine as well as flexed. With the addition of a load of two pounds, this activity generally increased to moderate when the forearm was supine and to slight when it was semiprone. However, there was generally no activity even with a load when the elbow was maintained in the flexed position with the forearm prone.

When extension without an added load was performed slowly, there was only slight antagonistic activity in the short head of the biceps if the forearm was kept supine, very slight if semiprone, and generally no activity if prone. Even with the added load, activity remained moderate in the supine and slight in the semiprone and prone positions. During quick extension, there was a burst of slight activity without the load and of moderate activity with the load, except when the forearm was prone; in the latter case there was merely slight activity even with a load.

Only if supination was strongly resisted did the short head of the biceps supinate the forearm when the elbow was in the extended position.

The short head of the biceps had slight activity during flexion of the shoulder joint when the forearm was in the supine or semiprone position. During maintenance of abduction of the shoulder at a right angle, there was activity in the short head of the biceps when the forearm was supine and the humerus was laterally rotated, but when the forearm was in the prone position and the humerus was still laterally rotated, this activity ceased.

On the whole, the short head of the biceps was less active than the long head during the various movements.

2. *Long Head of Biceps*

When flexion was performed slowly and without a load, the long head of the biceps flexed the supine forearm but acted only slightly on the semiprone forearm and not at all on the prone forearm. However, with the addition of a weight of two pounds, the semiprone forearm was flexed by this muscle with marked activity. With the forearm prone, the long head of the biceps was seen to have only slight activity even when the weight was lifted during slow flexion.

In quick flexion of the forearm, the long head of the biceps flexed the supine or the semiprone forearm with marked activity and the prone forearm with only slight activity.

During isometric contraction to maintain flexed postures of the elbow without added load, there was little, if any, activity in the long head of the biceps; but with the addition of the load, the activity increased to moderate, except when the forearm was prone and the elbow was flexed to 90 degrees. In this last position of the forearm, there was no activity in the long head of the biceps in over half of the subjects.

When extension without a load was performed slowly, there was generally slight to very slight activity when the forearm was in the supine or semiprone position and generally no activity when the forearm was in the prone position. With the added load, moderate to slight activity was seen with the forearm supine or semiprone, but there was only slight activity when the forearm was prone.

During quick extension the results were similar to those in the short head of the biceps which have been described.

The long head of the biceps supinated the forearm with the elbow extended only if resistance was applied against supination.

The long head of the biceps flexed the shoulder joint in both the supine and semiprone positions of the forearm. The muscle was active during maintenance of abduction of the shoulder joint only when the forearm was supine and the humerus was rotated laterally. When the forearm was pronated with little change in the position of the humerus, this activity disappeared.

In general, the actions of the long head of the biceps were similar to those of the short head of the biceps. The long head of the biceps was, however, generally more active than the short head during the various movements.

Brachialis

The brachialis is a flexor of the forearm in the supine, the semiprone, or the prone position in slow or in quick flexion, with or without added weight.

In slow flexion of the supine forearm, the brachialis acted along with the biceps; with the forearm in the semiprone or the prone position it was the main flexor. The brachioradialis showed only very slight activity with the forearm in the semiprone position during flexion, as will be shown.

As expected, the activity of the brachialis was greater when a weight was lifted during slow flexion of the forearm in any one of the three positions.

During quick flexion of the forearm in the three positions, it was markedly active.

The brachialis showed slight activity during isometric contraction to maintain flexion of the elbow without a load in the majority of the subjects regardless of whether

the forearm was supine, semiprone, or prone. With the added load, the activity remained slight to moderate when an angle of 90 degrees was maintained with the subject sitting, but increased to moderate when the angle was increased to 135 degrees with the subject lying supine.

During slow extension there was generally some slight antagonistic activity without the load, increasing only slightly when the load was added, regardless of whether the forearm was supine, semiprone, or prone.

Brachioradialis

When slow flexion of the elbow was carried out without weight, the brachioradialis did not show any activity during the movement, except when the forearm was in the semiprone position. In that position very slight activity was demonstrated.

If a load of two pounds was lifted, the muscle was moderately active during slow flexion of the forearm in the semiprone or prone positions. With the forearm in the supine position, even with an added weight, the muscle showed only slight activity during slow flexion.

During quick flexion of the forearm, however, even without a load, the muscle was active in all three positions of the forearm. It showed moderate activity in the supine and the prone positions and marked activity in the semiprone position of the forearm.

During isometric contraction to maintain the flexed position of the elbow without an added load, the brachioradialis was generally inactive; it showed slight activity in a minority of subjects only when the forearm was also semiprone. With the added load, there was an increase in activity, the greatest increase being seen when the forearm was in the semiprone or the prone position. With the forearm supine, no activity, even with the load, was demonstrated in about half of the subjects.

During slow extension, the brachioradialis generally showed little if any antagonistic activity unless there was a load. Even then, the greatest activity seen in brachioradialis was slight to moderate when the forearm was semiprone as the elbow was being extended.

The brachioradialis neither supinated the pronated forearm nor pronated the supinated forearm unless resistance was applied against the movements. Then, of course, the activity might very well indicate synergy rather than prime moving.

DISCUSSION

The results of the study provide convincing evidence that in the movements produced by the biceps, the brachialis, and the brachioradialis there is a fine interplay between them. This is to be expected. What is more striking, however, is the wide range of response from any one muscle in a series of twenty persons. Thus, although a general trend can be described, there is rarely any unanimity of action. For example, the brachialis is generally markedly active during quick flexion of the supine forearm, but in 5 per cent of the subjects it was completely inactive. Moreover, not only did the specific muscles show a range of responses in a series of subjects, but also a wide variation in the sequence of appearance and disappearance of activity during various movements. Contrary to expectation, the muscle that showed the greatest activity during a specific movement in an individual subject did not always come into play first or relax last.

These findings re-emphasize the general biological principle that there is a range of response in any phenomenon. It would seem that anatomists and clinicians have taken too little heed of this wide range of individual pattern of activity.

In this study, the long head of the biceps showed more activity than the short head in the majority of the subjects during slow flexion of the forearm, during supination of the forearm against resistance, and during flexion of the shoulder joint (although there was little difference between the activity of the two heads during isometric contraction

and during extension of the elbow). Sullivan, Mortensen, Miles, and Greene reported similar findings with surface electrodes during flexion only.

The biceps is generally active during flexion of the supine forearm under all conditions and during flexion of the semiprone forearm when a load of two pounds is lifted. However, with the forearm prone, in the majority of instances the biceps plays little if any role in flexion, in maintenance of elbow flexion, and in antagonistic action during extension, even with a load. Beevor stated that if the forearm is in supination, the biceps begins to act during flexion when there is a resistance of as little as four ounces, but that in a position of complete pronation it does not act until the resistance is at least four pounds. The results of the present study support Beevor's observations in regard to flexion; his observations were made, of course, without the help of electronics.

One reason that the biceps does not act on the prone forearm may be that because of its tendency to supinate the forearm during contraction, the biceps is reflexly inhibited. To maintain the prone position, afferent impulses from the pronating muscles, working through the central nervous system, result in a negative feed-back to the spinal centers which control the biceps.

The biceps is usually described as a supinator of the forearm. In this study, no activity in the muscle was demonstrated in the majority of the subjects during supination of the extended forearm through the whole range of movement if no resistance to supination was given. However, activity was observed in all the subjects when supination was strongly resisted. It follows that, generally, the biceps is not a supinator of the extended forearm unless supination is resisted.

It is necessary to explain why the biceps does not ordinarily supinate the extended forearm. It appears that because of the tendency of the biceps to flex the forearm, it is reflexly inhibited. Thus the extended position of the forearm is maintained while the supinator does the supinating. On the other hand, when supination is resisted, the biceps comes into strong action, and it was noted that usually the extended forearm is partly flexed as well.

The slight action of the biceps in flexion of the shoulder joint which was observed in this study confirms the accepted teachings concerning the action of this muscle at the shoulder. Because of the difficulty in divorcing supination of the forearm from lateral rotation of the humerus, no final conclusions can be drawn in regard to the textbook statement that the long head of biceps is an abductor of the arm. In our study, when the forearm was in the prone position, there was relatively no change in the humerus; yet there was a dramatic disappearance of activity in the biceps. This suggests that the textbook statement is, at best, questionable.

The brachialis has been generally and erroneously considered by anatomists to be a muscle of speed rather than one of power because of its short leverage. In this study it was found to be a flexor of the supine, semiprone, and prone forearm in slow or quick flexion, with or without an added weight. McGregor has correctly described this muscle as a "flexor *par excellence* of the elbow joint." Apparently it is called upon to flex the forearm in all positions because the line of its pull does not change with pronation or supination.

Both maintenance of specific flexed postures of the elbow, that is, isometric contraction, and the movement of slow extension when the flexors must act as antagonists generally bring the brachialis into activity in all positions of the forearm. This is not the case with the other two muscles. Thus, the brachialis may also be designated the workhorse among the flexor muscles of the elbow.

The short burst of activity generally seen in all the muscles during quick extension can hardly be considered antagonistic in the usual sense. Nonetheless, it is helpful, here, to invoke the current and probably valid concept of the stretch reflex which holds that the burst of activity in the antagonists provides a protective function for the joint. (It

may be noted that the biceps is particularly active during quick extension with an added load.)

The brachioradialis has been described as a flexor of the forearm, acting to its best advantage in the semiprone position of the forearm. It was found in this study that, in a majority of subjects, the brachioradialis does not play any appreciable role during maintenance of elbow flexion and during slow flexion and extension of the forearm when the movement is carried out without a weight. When a weight is lifted during flexion of the forearm, the brachioradialis is generally moderately active in the semiprone or prone position of the forearm and is slightly active in the supine position of the forearm. There is no comparable increase in activity with the addition of weight during maintenance of flexion and during slow extension. It was also found that in most instances the brachioradialis is quite active in all three positions of the forearm during quick flexion and extension. It follows that the muscle is a reserve for occasions when speedy movement of the forearm is required and when weight is to be lifted, especially in the semiprone and the prone positions of the forearm. In the latter position, the biceps usually does not come into prominent action.

The brachioradialis is a smaller muscle than the biceps or the brachialis, but it can be a powerful elbow flexor. Both its origin and insertion are far removed from the axis of motion of the elbow. Regardless of whether the proximal or distal bone is being moved, the power arm is quite long, at least when the elbow is held in the position of 90 degrees of flexion or thereabouts. On the other hand, with lesser amounts of flexion the angle of pull of the brachioradialis is small, which in effect makes the power arm short. In the early stages of flexion, therefore, this muscle can produce a rapid whiplike action.

The brachioradialis has been sometimes described as a supinator of the prone forearm and a pronator of the supine forearm acting up to the semiprone position in both cases. The results of this study show that it neither supinates nor pronates the extended forearm unless these movements are done against resistance. Here, at most, it acts only as an accessory muscle, coming into action when strength is required to supinate or to pronate the forearm. More probably, it acts only as a synergist.

From the observations made, it would seem that the biceps, the brachialis, and the brachioradialis differ in their activity in the three positions of the forearm during flexion. It was noted, however, that all three muscles act maximally when a weight is lifted during flexion of the semiprone forearm. The semiprone position of the forearm has been described as the natural position of the forearm, the position of rest, the position of greatest advantage for most functions of the upper limb [2]. The findings of this study show, in fact, that this is the position in which all the muscles are maximally active when a weight is lifted during flexion of the forearm.

In several subjects, complete absence of activity in the three flexors during maintenance of flexed postures without a load when the forearm was semiprone or prone was noted. The likely explanation of this is that some other of the muscles at the elbow act sufficiently in some persons to relieve the regular flexors. Proof of this requires further study.

Finally, attention should be drawn to the finding that, with the forearm at rest, none of the muscles exhibit any activity. This, of course, has been a universal experience in electromyographic studies of resting muscle but has not been sufficiently emphasized.

SUMMARY AND CONCLUSIONS

A detailed electromyographic investigation of the actions of the biceps brachii (both heads), the brachialis, and the brachioradialis was carried out in twenty normal young adults with a Stanley Cox multi-channel electromyograph equipped with audio and cathode-ray units and a thirty-five-millimeter linagraph camera. Records on film were made simultaneously from four bipolar concentric-needle electrodes in each subject during

a large variety of movements and positions of the upper limb with and without a load of two pounds.

For each muscle and for each movement or posture a general trend could be determined. However, what proved most striking was the wide range in the degrees of activity in the series and in the sequence of appearance and disappearance of activity during various movements. An appreciable number of muscles differed from the average or general trend for any movement.

The muscles were completely inactive when the forearm was in the relaxed or resting position.

The conclusions presented indicate the general trend of the behavior of these muscles in the majority of the subjects.

The short and long heads of the biceps have similar, although not identical, actions except that the long head of the biceps is generally more active in most of the movements.

The biceps is a flexor, both isometric and isotonic, of the supine forearm under all conditions and is a flexor of the semiprone forearm when a load is lifted. However, it plays little or no part in the flexion of the prone forearm even when a load of two pounds is lifted.

The biceps (both heads) is not a supinator of the extended forearm unless supination is firmly resisted; ordinary supination is performed chiefly by the supinator.

The biceps takes part in flexion of the shoulder joint, showing a slight activity in both heads, but it is not active in abduction unless the forearm is supinated.

The brachialis is active during flexion of the forearm under all conditions and is generally active during most movements and postures. It is a flexor *par excellence* and is the workhorse of the elbow joint.

The brachioradialis comes into action either during quick flexion of the forearm or when weight is lifted during slow flexion, especially of the semiprone and prone forearm. It is a reserve which is called upon when quick or powerful movements are required.

The brachioradialis acts neither in supination of the extended prone forearm nor in pronation of the extended supine forearm unless these movements are strongly resisted.

All three muscles act simultaneously, with the greatest activity when weight is lifted during flexion of the semiprone forearm.

The antagonistic activity of the muscles during slow extension shows variable patterns, with the brachialis generally always active. During quick extension, the short, sharp burst of activity (found in all the muscles, but most pronounced in the biceps) probably is the result of a protective stretch reflex.

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Bone Implants

Preliminary Report of an Experimental Study * †

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INTRODUCTION

The purpose of the following study was to compare the rate of healing of a standard bone defect following implantation of (1) frozen homogenous bone, (2) inorganic bone salts prepared by deproteinizing homogenous bone, and (3) organic bone matrix prepared by decalcifying homogenous bone.

In a previous series of experiments [10] survival of grafts of fresh autogenous and fresh homogenous bone was studied following grafting to the anterior chamber of the eye in rats

TABLE I

Summary of Material

Type of Implant	No. of Defects Implanted	Age of Host Rat at Operation (*Days*)	Duration of Implant (*Days*)
Frozen intact bone	18	202–254	42
Deproteinized bone	12	183–282	42–43
Decalcified bone	12	181–230	42–43

and guinea pigs. The results of these experiments revealed that fresh autogenous grafts survived and that over a period of six weeks new bone was laid down in association with the grafts. In contrast to this, grafts of fresh adult homogenous bone to the anterior chamber of the eye underwent necrosis in the majority of instances, and there was a lymphocytic plasma-cell-fibroblastic response on the part of the host. However, homogenous grafts of embryonic bone to the anterior chamber of adult rat eyes did survive and grow. The reaction of the host to implants of frozen non-viable homogenous adult bone appeared to be less marked than the reaction to living homogenous grafts; in no case was new-bone formation observed in response to non-viable implants (in contrast to the findings of Urist and McLean).

The classic experiments of Axhausen, Barth, Marchand, Gallie, Phemister, and others [3] have all demonstrated that dead bone may undergo replacement by new bone arising from the host when implanted into bone; clinical observations have amply documented the fact that dead bone—autogenous, homogenous, or even heterogenous—may be used successfully (that is, will be replaced by living bone) when implanted into living bone. Since dead bone is a heterogenous system of organic matrix and inorganic salts, the purpose behind the present study was to determine which of the various components is most readily replaced.

It has been suggested that the answer to this question may be found in the inorganic-salt component [8,16]; Wells even contended that, "Calcium salts exert a specific influence on the connective tissue cells which causes them to assume active growth and to undergo a metaplasia not only into osteoblasts and bone corpuscles but even into marrow cells with

* Read at the Annual Meeting of The American Orthopaedic Association, Banff, Alberta, Canada, June 22, 1956.

† The experimental studies presented in this paper were carried out under a National Institute of Health Grant in Aid, Number A-726 (C3).

TABLE II

DEGREE OF DEFECT HEALED AS SEEN BY ROENTGENOGRAMS

Type of Implant	Minimal	⅓	⅔	Complete
Frozen intact	16	2		
Deproteinized	12			
Decalcified	1	4	2	5

TABLE III

EVALUATION OF HISTOLOGICAL SECTIONS

Type of Implant	Endothelial Invasion of Implant	Incorporation of Implant in New Bone	Foreign-body Reaction
Frozen intact	None to minimal	None to minimal	Moderate round cells
Deproteinized	Minimal	None to minimal	Occasional round cells
Decalcified	Minimal to moderate	About half of the implants incorporated	Occasional round cells

hematogenic function"—a statement apparently based on an experiment by Barth who reported that new bone formed following implantation of bone ash into the abdominal cavity of a cat.

MATERIAL AND METHODS

Operation

Initially defects were made in the iliac crests of young pigs, but this proved unsuccessful because of subsequent fractures of the ilium. An attempt was then made to create standard defects in the long bones of dogs and cats, but the problem of immobilization and of standardizing the defect proved difficult to solve. Trephine defects in the parietal bones of the rat calvarium subsequently proved to be more satisfactory. Defects were made in each parietal bone lateral and anterior to the median and interparietal sutures to avoid the underlying venous sinuses. The drill was driven by a low-speed dental engine. A small

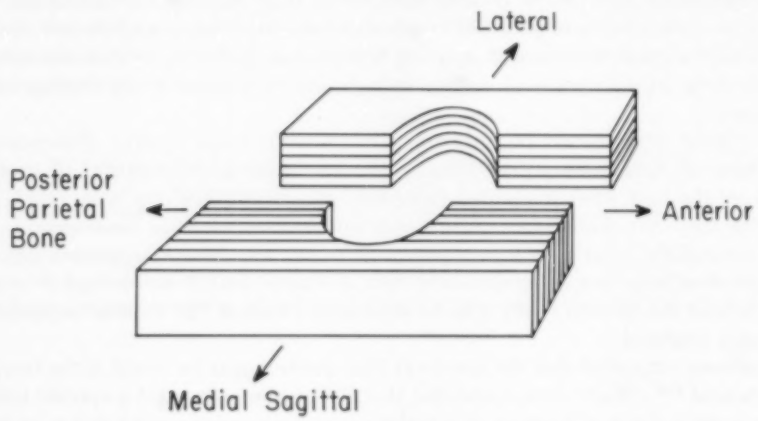

FIG. 1

Schematic diagram to illustrate the method of histological sectioning. Prior to embedding, the parietal bone was divided through the trephine defect as shown. The two halves were then sectioned in the planes as indicated (the lateral portion in a coronal plane and the medial portion in a median plane). In the following photomicrographs the plane of section as described is *A* (coronal) or *B* (median).

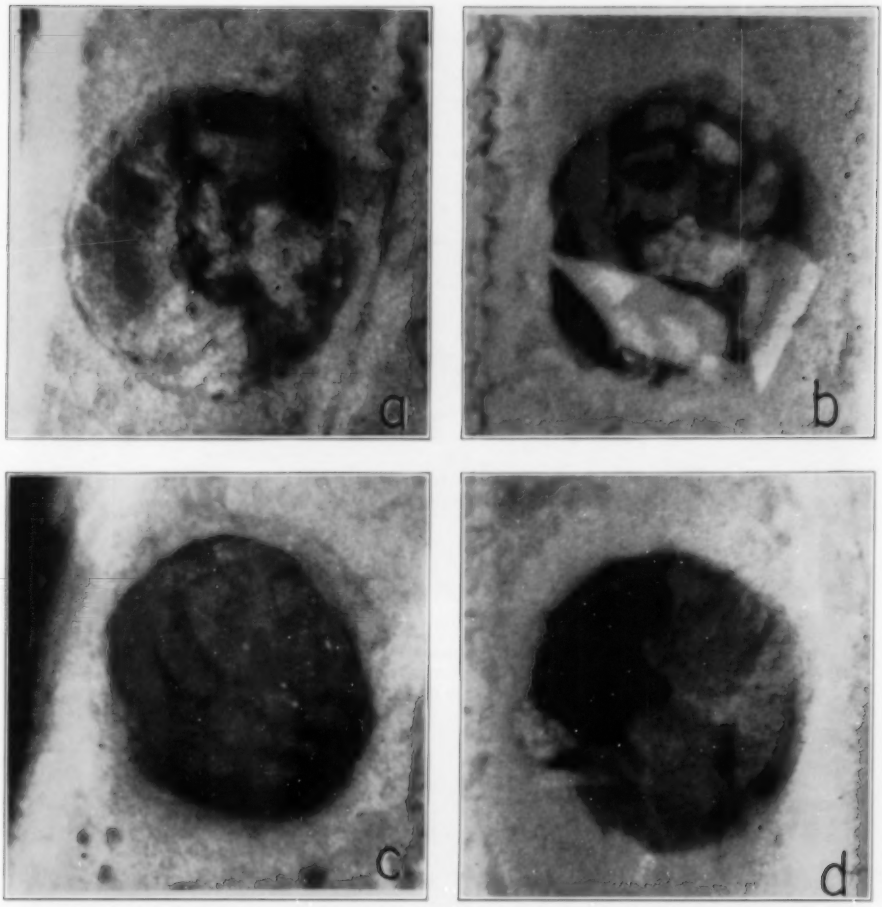

FIG. 2

Representative roentgenograms (× 15) of the trephine defects in the parietal bones of adult rats six weeks following operation: *a*, defect grafted with fresh autogenous cancellous bone; *b*, defect implanted with frozen homogenous bone; and *c*, defect filled with inorganic salt. (In the case illustrated, the inorganic salt used was calcium sulphate; the appearance, however, is similar to that seen when the defect was implanted with deproteinized bone. There is minimal new-bone formation around the margins; the opacity in the central portion of the defect represents the implanted salt.) *d*, defect implanted with decalcified bone matrix (the radiopaque material bridging the defect represents new-bone formation since the implants were radiolucent).

shoulder prevented penetration into the underlying meninges and brain. Drilling was carried out intermittently, and the wound was flushed with isotonic saline to minimize heat necrosis. After both tables of the skull had been cut, the circular chip was removed, and the defect was filled to the level of the outer table with the implant material. The wound was closed in layers with interrupted sutures of silk.

Preparation of the Implants

Frozen intact homogenous bone (eighteen defects): Bone, obtained from the fibulae of young adult rats of the same strain, was aseptically removed and transferred to sterile pyrex tubes containing Hank's solution, penicillin, and streptomycin. The tubes were glass-sealed, immersed in a solution of dry ice and alcohol in a Dewar flask (−78 degrees

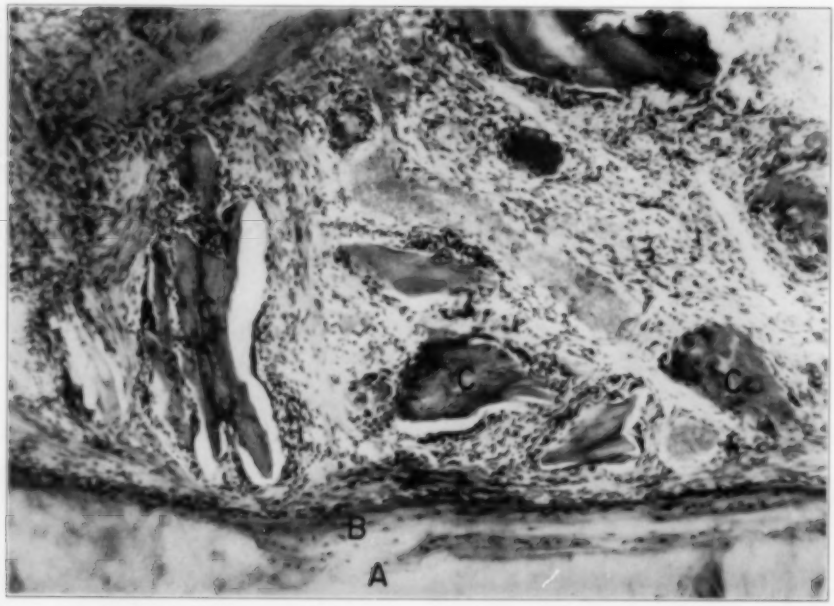

FIG. 3

Photomicrograph (× 145) of frozen homogenous implants, defect section in *A* plane. (*A*, margin of defect; *B*, new-bone formation; and *C*, implants.) There is no evidence of new-bone formation around the implants except where they come in contact with host bone.

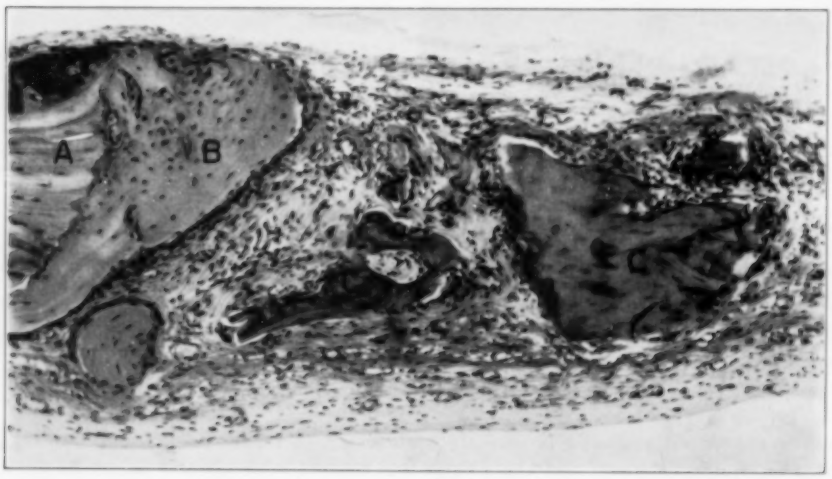

FIG. 4

Photomicrograph (× 145) of frozen homogenous implants, defect sectioned in plane *B*. (*A*, margin of defect; *B*, new-bone formation; and *C*, implants.) Figure illustrates the mild foreign-body reaction around the implants.

centigrade), and stored for fourteen to twenty-two days. After having been thawed, the fibulae were fragmented and implanted immediately into the recipient defects.

Deproteinized bone (twelve defects): Fibular bone, frozen for three days, was deproteinized by extraction in a Soxhlet extractor with approximately twenty milliliters of an 80 per cent aqueous solution of ethylene diamine for six hours (thirty-six cycles). It was then

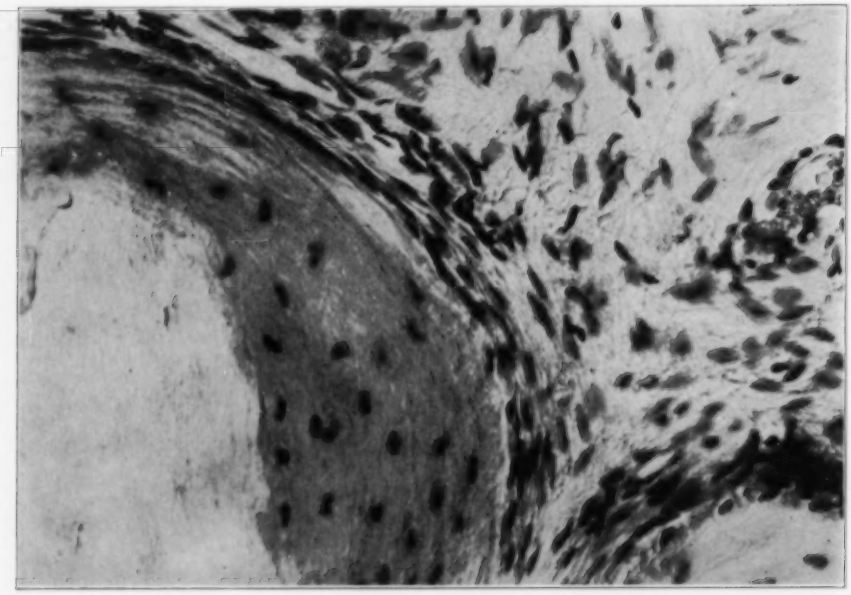

FIG. 5

Photomicrograph (× 930) of frozen homogenous implants. Figure illustrates the junction between new-bone formation (which on serial section could be traced to the margins of the trephine defect) and the implants. The type of foreign-body reaction to one of the implants can be seen in the lower right-hand corner.

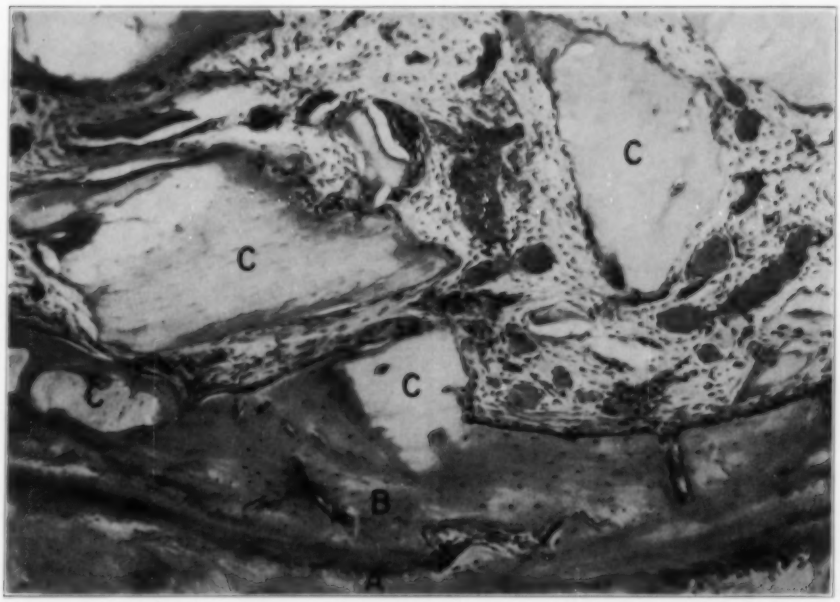

FIG. 6

Photomicrograph (× 145) of deproteinized implants, trephine defect sectioned in plane *A*. (*A*, margin of defect; *B*, new-bone formation; and *C*, implants). Figure illustrates incorporation of the implants into the marginal new-bone formation. New-bone formation, however, is minimal, and there is evidence of a mild foreign-body reaction around the implants in the central portion of the trephine defect. (The apparent shrinkage in this section and the section illustrated in Fig. 7 is due to the fact that the implants were composed predominantly of inorganic salts which were removed during decalcification prior to sectioning.)

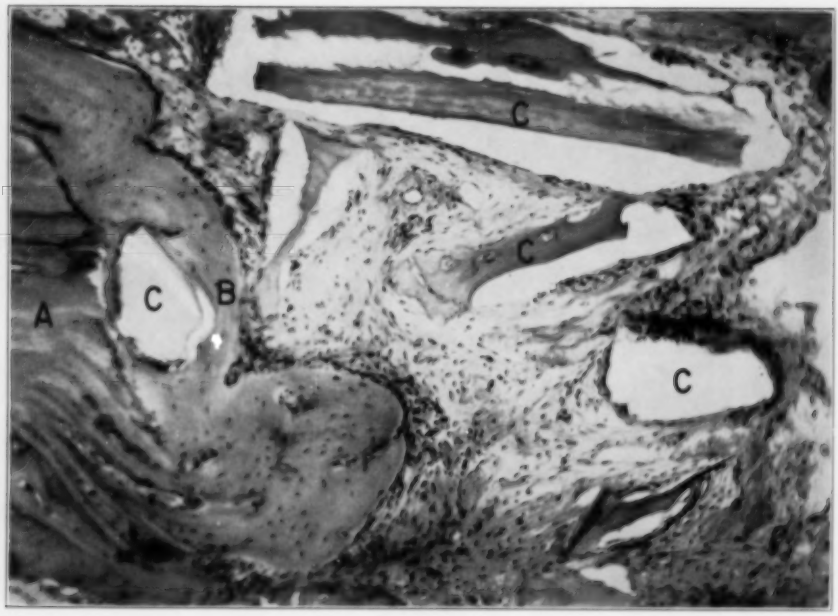

FIG. 7

Photomicrograph (× 145) of deproteinized implants, defect sectioned in plane *B*. (*A*, margin of defect; *B*, new-bone formation; and *C*, implants.) Figure illustrates incorporation of one of the implants in new bone at the margin of the defect and the foreign-body reaction.

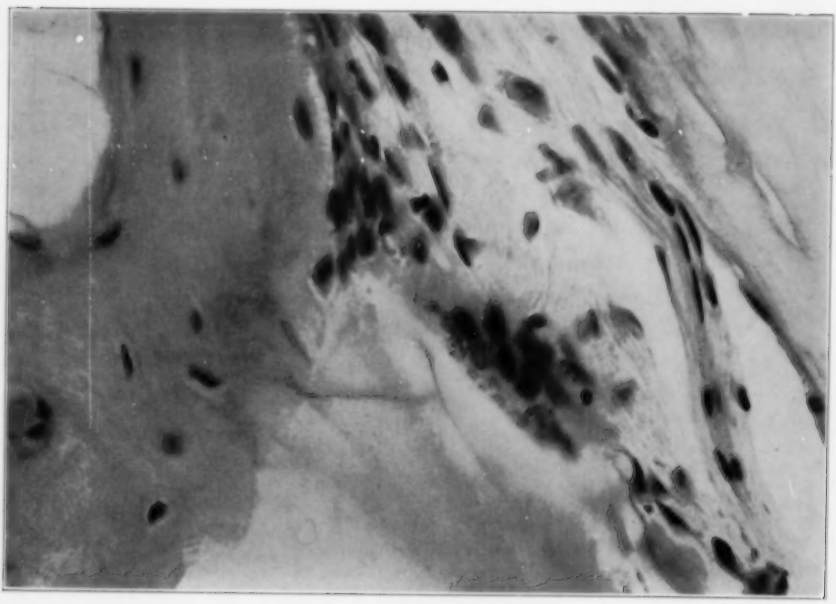

FIG. 8

Photomicrograph (× 930) of deproteinized bone implants, showing the junction between the implants and the host new bone, and the foreign-body reaction.

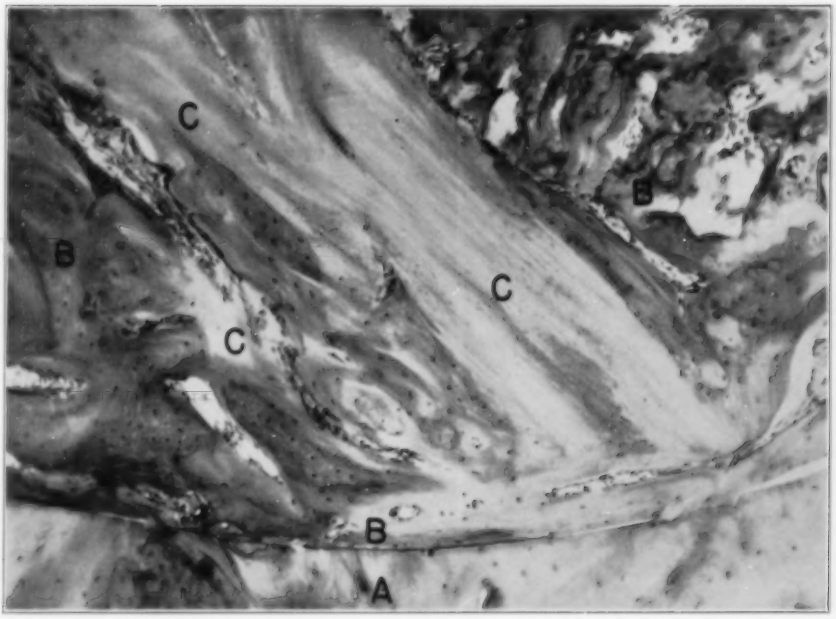

FIG. 9

Photomicrograph (× 145) of decalcified bone implants, defect section in plane *A*. (*A*, margin of defect; *B*, new-bone formation; and *C*, implants.) Implants have been incorporated into relatively abundant new-bone formation.

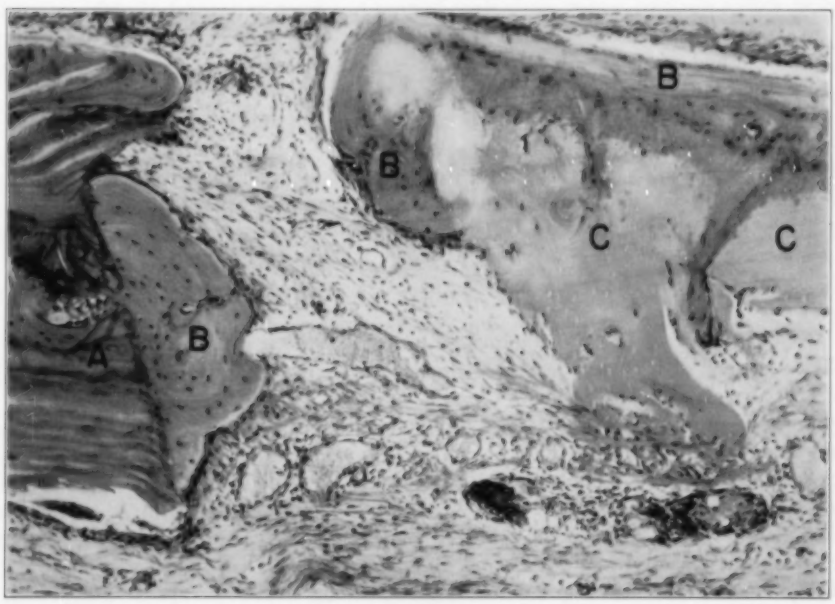

FIG. 10

Photomicrograph (× 145) of decalcified bone implants, defect sectioned in plane *B*. (*A*, margin of defect; *B*, new-bone formation, and *C*, implants.) The implant is partially surrounded by new bone. Vascular and osseous invasion of the implants and replacement by new-bone formation is much more extensive than that in the two preceding types of implants.

FIG. 11

Photomicrograph (× 930) of deproteinized homogenous implants showing the junction between host new bone and the implants. Endothelial invasion of the implants and apparent ready incorporation into or replacement by new bone is illustrated.

rinsed in sterile distilled water, each rinse lasting one hour or a total of eighteen cycles, and transferred to a sterile container and stored dry at 4 degrees centigrade until implantation. This method of deproteinization followed that described by Williams and Irvine who cited the following advantages:

1. Simple removal of the solvent because of the solubility of ethylene diamine in water;

2. Comparable chemical analysis for the crystals when bone was extracted with ethylene diamine or dry ashed at 550 degrees centigrade in a muffle furnace (the main difference being in the amount of carbonate present—ashing apparently removed more carbonate than ethylene diamine extraction);

3. X-ray diffraction patterns gave the same spacing as for crystals prepared by other methods;

4. Kjeldahl nitrogen analyses indicated a nitrogen content of less than 0.1 per cent;

5. Avoidance of high temperatures which could alter the crystalline as well as the gross structure.

Decalcified homogenous matrix (twelve defects): Fibular bone was frozen at −10 degrees centigrade in Hank's solution for three to nine days and was then decalcified in a saturated 10 per cent solution of the disodium salt of ethylene diamine tetra acetic acid * at room temperature for a period of twelve days. The versene solution was removed by repeated washing with normal isotonic saline solution. The bone was then stored at 4 degrees centigrade for approximately three days before implanting.

Recipient rats: Of the twenty-three young adult Long-Evans rats operated on, twenty-one were used for the final study (a total of forty-two defects). In two of the rats infections

* Ethylene diamine tetra acetic acid (versene) has been used in our laboratory for several years to decalcify bone for histological sectioning. It is bacteriostatic, stable at high temperatures, and relatively nontoxic.

developed; these were eliminated from the final series. A summary of the grouping is given in Table I. All animals were maintained on the standard laboratory diet for six weeks. After six weeks, the rats were killed with ether anaesthesia; the calvarium was removed and x-rayed, following which it was fixed in Bouin's fluid, decalcified, dehydrated, embedded in celloidin, and sectioned at seven micra (Fig. 1).

RESULTS

Frozen homogenous bone: Roentgenographically one-third of the trephine defect was filled with new bone in two of the eighteen rats; minimal bone proliferation was observed in the remaining sixteen (Table II). On histological examination (Table III and Figs. 4 and 5) in some places the margins of the implants were covered with new bone; in other areas there were clusters of round cells and multinucleated giant cells. Apparently active resorption of the implants was taking place.

Inorganic salts: Defects in which the deproteinized bone was implanted failed to show more than minimal amounts of new-bone formation roentgenographically (Table II). Histological sections (Table III and Figs. 6, 7, and 8) revealed that in some the implants were incorporated into the narrow margin of new-bone formation around the edge of the defect. There was minimal foreign-body reaction.

Organic matrix: Following implantation of the decalcified bone matrix in the twelve defects, complete bridging with new bone occurred in five, two-thirds of the defect was filled with new bone in two, and one-third in four; the remaining defect showed only minimal evidence of repair (Table III). Histologically the implanted fragments were well incorporated in the host bone (Table III and Figs. 9, 10, and 11) and endothelial elements had invaded most of the fragments. There was no appreciable foreign-body reaction *.

DISCUSSION AND CONCLUSIONS

Of the various materials used, it would appear that the best substitute for fresh autogenous-bone grafts (if mechanical factors are not a consideration) is the organic matrix of bone devoid of its inorganic salt. This conclusion, incidentally, is not new. Nicholas Senn came to the same conclusion in 1889 on the basis of a series of experiments in which he filled bone defects with heterogenous bone previously treated with dilute hydrochloric acid. To quote Senn: "Antiseptic decalcified bone is the best substitute for living bone grafts and the restoration of loss of substance in bone . . . [such a] packing furnished the best medium for the growth and development of the tissue resulting from the regenerative process initiated by the trauma." Miller, in a clinical report in 1890, stated that pieces of ox ribs, decalcified with dilute hydrochloric acid and sterilized by soaking in dilute carbolic acid, appeared to be superior to fresh bone in obtaining repair of a tibial defect.

Apparently successful replacement of an implant depends on the readiness with which it can be invaded by vascular elements. The presence of inorganic salts in the implant would appear to impede rather than accelerate the process of replacement. In this connection Cohen, Maletskos, Marshall, and Williams reported that a study of the fate of bone grafts by means of radioactive tracers revealed that all of the calcium incorporated into the callus came by way of the circulating blood from skeletal sources situated throughout the body rather than through diffusion from the graft. Whether any antigenic factors are present in decalcified matrix implants or whether the organic matrix can be further fractionated has not yet been determined.

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Variations in Normal Bone-Marrow Pressures*

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In a study of ways to increase the circulation in bone, we found it necessary to investigate the normal pressures in the intramedullary canals of the long bones. A review of the literature revealed that some observations had previously been made on diaphyseal pressure and its fluctuations. Larsen, while studying diaphyseal necrosis in 1938, made some observations on intramedullary pressure in the femora of eight dogs. The recordings, made with a mercury manometer, revealed a pressure of thirty to forty millimeters of mercury and showed fluctuations related to arterial pulsation. Kalser and associates, studying marrow-pressure changes under high altitude conditions in 1951, and Bloomenthal and associates, studying fat embolism in 1952, observed the normal pressures in the femoral diaphyses of dogs. The study of Kalser and associates showed that the normal diaphyseal pressure of anaesthetized dogs varied from 12 systolic, 8 diastolic to 117 systolic, 96 diastolic, the average being 52 systolic, 41 diastolic. This study also showed that there was no correlation between the systemic blood pressure and the diaphyseal bone-marrow pressure. In the study of Bloomenthal and associates, it was found that the intramedullary pressure averaged fifty millimeters of mercury, the range being from twenty to 115 millimeters.

FIG. 1

Vitallium bone cannulae inserted in the epiphyses and diaphyses of a tibia and a femur.

Larsen, and Bloomenthal and associates observed that changes occurred in the diaphyseal marrow pressure and systemic blood pressure when various drugs were used. Adrenalin and pituitrin produced a fall in the diaphyseal pressure with a simultaneous rise in systemic blood pressure. Histamine produced a fall in both systemic blood pressure and diaphyseal marrow pressure, while ephedrine and benzedrine produced a rise in both systemic and marrow pressure.

The only observations on human subjects that we have found are those of Miles. In 1955, he reported his observations on the pressure in the femoral heads of over thirty individuals undergoing operation for reconstruction or repair following fracture of the femoral neck. Pressures of forty to fifty centimeters of saline were observed, and fluctuations related to arterial pulsation were frequently seen. Miles thought that the presence or absence of arterial pulsations might be of some value in determining the future viability of the femoral head.

As a preparatory step in experiments on increasing the blood supply to the long bones, we found it necessary to study the normal intramedullary pressure in dogs. The purpose of this report is to point out the normal diaphyseal pressures and the normal variations

* Read at the Annual Meeting of the Orthopaedic Research Society, Chicago, Illinois, January 25, 1957.

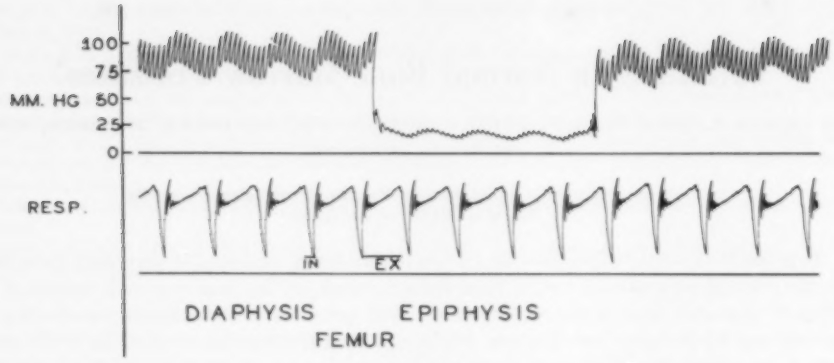

CHART I

The bone-marrow pressure and the respiration rate were recorded simultaneously. The recording showing the marrow pressure, first in the diaphysis, then in the epiphysis, and then in the diaphysis again, was obtained by the same manometer, a three-way valve being used to make the rapid switches. Note that the fluctuations in the marrow pressure are synchronous with the respiratory phases.

and to describe the normal relationships between diaphyseal and epiphyseal pressures in the femora and tibiae of adult dogs.

METHODS

We used the Sanborn electromanometer, with water as the connecting medium, to record the marrow pressures. The Offner multi-recorder was employed to transcribe the records. In some of our early experiments we also measured pressures with the saline and mercury manometer, but this method was later abandoned in favor of the electrical transducer which is far more sensitive.

Pressure studies were made in seventeen dogs ranging from eleven to forty-eight pounds in weight. In this group there were eleven males and six females. Each dog was

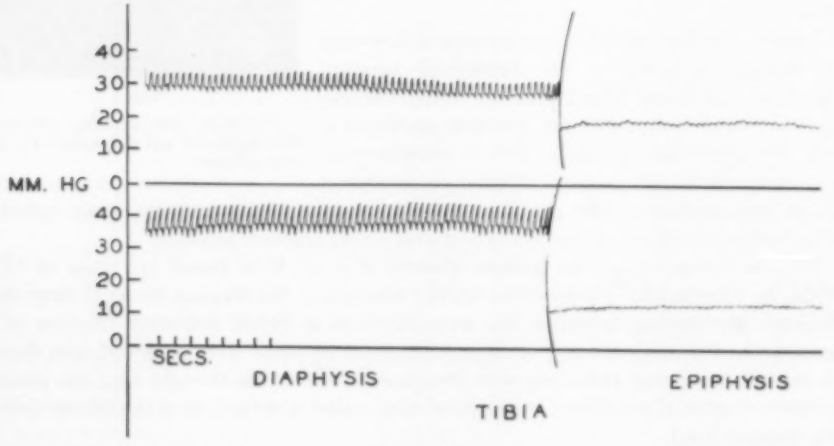

CHART II

Concurrent recordings were obtained from the diaphyses and epiphyses of both tibiae of the same dog. The switch from diaphysis to epiphysis was made by a three-way valve. The dicrotic nature of the diaphyseal pulse wave should be noted as well as the relative absence of respiratory-phase fluctuations. The absence of these fluctuations was probably the result of the deep state of anaesthesia in this particular dog.

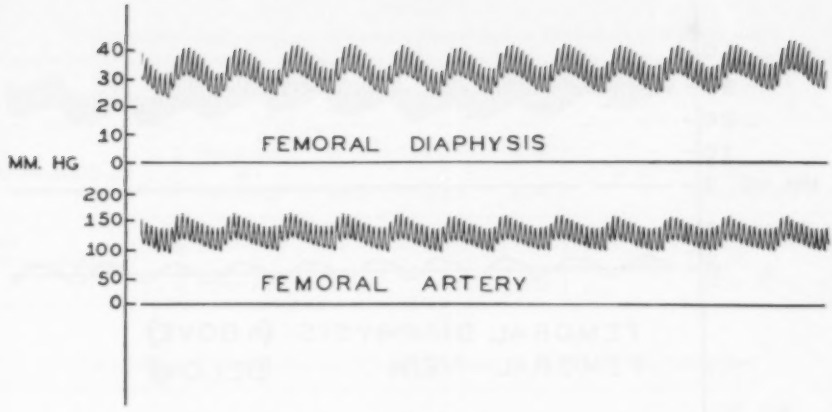

CHART III

Simultaneous recordings of the pressures in the femoral diaphysis and the ipsilateral femoral artery.

anaesthetized with nembutal (thirteen milligrams per pound given intravenously), and an anticoagulant (heparin, ten milligrams per twenty pounds injected intravenously) was used to prevent clotting of the blood in the bone cannula. The heparin was not given until after the bones to be studied had been exposed.

The pressures in the diaphyses of both the tibia and the femur were measured, concurrent and simultaneous measurements being made of the pressures in the proximal tibial epiphysis and the distal femoral epiphysis, respectively. The concurrent observations made in each bone were recorded by the same manometer, a three-way valve being used in order to switch quickly from diaphysis to epiphysis. In some dogs marrow-pressure

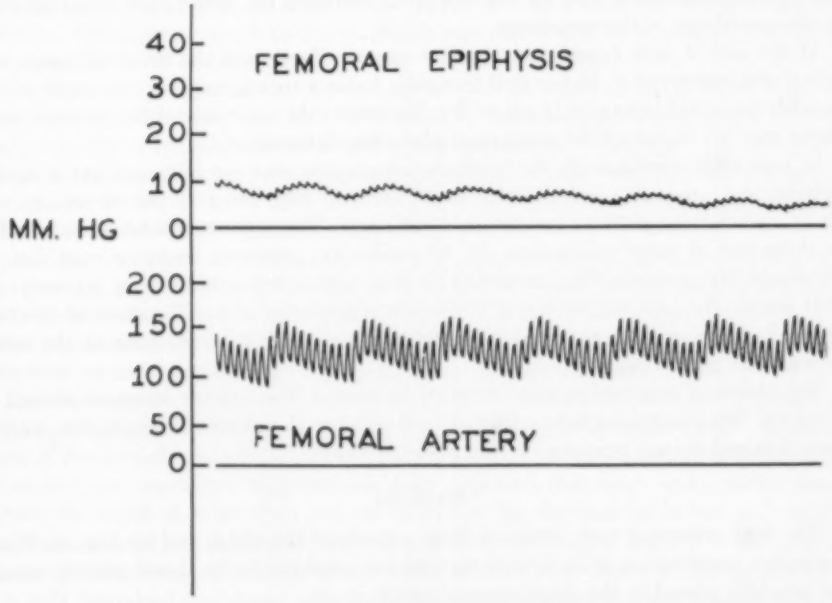

CHART IV

Simultaneous recordings of the pressures in the femoral epiphysis and ipsilateral femoral artery. These recordings are from the same dog as those in Chart III.

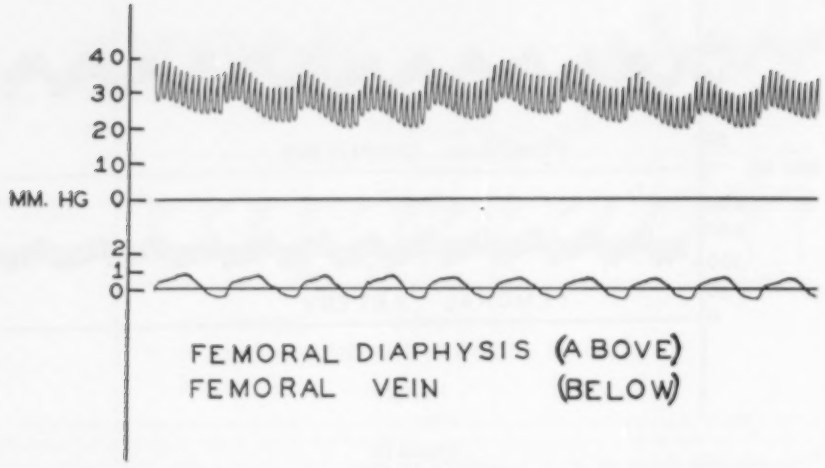

CHART V
Simultaneous recordings of the pressures in the femoral diaphysis and the ipsilateral femoral vein.

recordings were made simultaneously with recordings of femoral-artery pressure, femoral-vein pressure, or the phases of respiration.

The technique of determining the pressures was as follows. A 0.28-centimeter hole was drilled through the cortex five minutes after the heparin had been given. When a free flow of blood was obtained, a small Vitallium tap, threaded at one end, was screwed into the hole. The lead tube of the manometer was then attached to the tap by means of a one-centimeter length of polyethylene tube. The dogs and recording tubes were securely fastened and carefully observed so that no extraneous motion could affect the recordings. Leaks in the connections and air bubbles were searched for, since they could seriously alter the sensitivity of the recordings.

At the end of each experiment the dog was sacrificed, and the involved bones were removed and preserved in 10 per cent formalin. Later a roentgenogram was made of each bone with the metal tap again in place. By this means the exact site of the pressure measurement and the status of the epiphyseal plate was determined.

In making the recordings the Sanborn manometer was carefully calibrated against a mercury manometer at sensitivities of 20, 40, and 100. Most of the recordings were made at a sensitivity of 40 on curvilinear ruled paper. The manometers were set for a full-scale deflection of forty millimeters. At 40 sensitivity, pressures could be read directly; at 20 sensitivity, a one-millimeter deflection represented 0.5 millimeter of mercury; and at 100 sensitivity, one millimeter of deflection represented 2.5 millimeters of mercury. Almost all of the recordings were made with the recording paper running at the rate of 0.5 centimeter per second.

The phases of respiration were recorded by means of a canister strapped around the dog's chest. The excursions were adjusted to show only the phases of respiration, and the figures obtained do not represent actual pressure values.

FINDINGS

The data presented were obtained from a study of ten tibiae and six femora. Roentgenographic examination of each bone showed the epiphysis to be closed and the cannula to be properly placed in the diaphysis and epiphysis.

The presence of pressure was observed in the diaphysis and epiphysis of each of the bones studied, and fluctuations corresponding to the arterial pulse were observed and

TABLE I

CONCURRENT COMPARISON OF MAXIMUM PRESSURES IN DIAPHYSIS AND EPIPHYSIS

		Mean	S.D.	S.E.	S.E. diff. M.	t
Tibia (29 observations)	Diaphysis	51.7	28.48	5.28	5.37	7.40
	Epiphysis	12.0	5.13	0.96		t (P. 0.05) = 2.05
Femur (18 observations)	Diaphysis	32.2	8.79	2.07	3.03	4.45
	Epiphysis	18.8	9.38	2.21		t (P. 0.05) = 2.11

TABLE II

CONCURRENT COMPARISONS OF PULSE PRESSURES IN DIAPHYSIS AND EPIPHYSIS

		Mean	S.D.	S.E.	S.E. diff. M.	t
Tibia (29 observations)	Diaphysis	7.6	3.99	0.74	0.75	9.16
	Epiphysis	0.69	0.76	0.14		t (P. 0.05) = 2.05
Femur (18 observations)	Diaphysis	5.0	2.46	0.58	0.78	4.24
	Epiphysis	1.7	2.23	0.52		t (P. 0.05) = 2.11

recorded. The pulse wave in the diaphysis was usually dicrotic and was always higher than that in the epiphysis.

In multiple concurrent observations, comparing the pressures in the same bone, it was found that the marrow pressure in the diaphysis was always higher than that in the epiphysis. The pulse pressure in the diaphysis was also found to be greater than that in the epiphysis.

In twenty-nine observations on ten tibiae, it was found that the mean maximum pressure in the diaphysis was 51.7 millimeters of mercury, while the mean maximum pressure in the epiphysis was 12.0 millimeters of mercury. The pulse pressure in the diaphysis was found to be 7.6 millimeters of mercury, while that in the epiphysis was found to be 0.69 millimeter of mercury. These differences in pressure are significant at the 5 per cent level (Tables I and II).

In eighteen concurrent observations on six femora, it was found that the mean maximum pressure in the diaphysis was 32.3 millimeters of mercury, while that in the epiphysis was 18.8 millimeters of mercury. The mean pulse pressure in the diaphysis was five millimeters of mercury, while that in the epiphysis was 1.7 millimeters of mercury. These differences are also significant at the 5 per cent level (Tables I and II).

In almost every bone studied we observed rhythmical fluctuations in pressure in both the diaphysis and epiphysis. These fluctuations corresponded to the respiratory phases of the animals. Usually there was a decrease in pressure associated with inspiration and an increase associated with expiration. It appeared that there was a direct relation between the depth of respiration and the degree of the fluctuations in the bone marrow. The mean value of the respiratory fluctuations in the diaphysis was 2.2 ± 1.1 (standard deviation) millimeters of mercury, while that of the fluctuations in the epiphysis was 0.9 ± 0.74 (standard deviation) millimeter of mercury. This difference between diaphysis and epiphysis was not significant. The pressure fluctuations associated with respiration were found to be similar in the diaphysis, epiphysis, femoral artery, and femoral vein.

In studies on the tibia, clamping of the femoral artery produced an immediate and abrupt fall of pressure in the epiphysis and diaphysis, the relative change being greater in the diaphysis. There was also a complete obliteration of the pulse wave in both the epiphysis and diaphysis. Clamping of the femoral vein produced prompt rises in the pressure in the epiphysis and diaphysis. The rise in the epiphysis was relatively greater, but there was no significant variation in the pulse pressures.

CONCLUSIONS

1. In the same bone, and under similar physiological conditions, the mean systolic marrow pressure in the diaphysis is significantly higher than the mean systolic marrow pressure in the epiphysis.

2. In the same bone, and under similar physiological conditions, the pulse pressure in the diaphysis is significantly greater than the pulse pressure in the epiphysis.

3. There is a rhythmical fluctuation in the marrow pressure in the diaphysis and epiphysis which is synchronous with the phases of respiration. The fluctuations are most pronounced during forceful expiration.

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Some Mechanical Tests on the Lumbosacral Spine with Particular Reference to the Intervertebral Discs

A Preliminary Report *

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INTRODUCTION

Low-back and sciatic pain has long puzzled the medical profession. An imposing list of possible causes for this syndrome has been compiled which implicates various joint and ligamentous structures in the lumbosacral region, the spinal-nerve roots, the muscles and fascia of the lumbar area, the local fatty tissues, the abdominal aorta and iliac vessels, and the pelvic and abdominal viscera. However, convincing pathological and anatomical evidence to incriminate these various structures is frequently not to be found in patients who complain of low-back and sciatic pain.

Since the demonstration of rupture of an intervertebral disc as a cause of low-back and sciatic pain [32], there has been a growing tendency among orthopaedic and neurological surgeons, in the absence of other demonstrable cause, to attribute low-back pain to derangements of one or more of the lumbar intervertebral discs. However, if this assumption is true, the mechanism by which pain is produced is not apparent in many instances. An extensive literature concerning the intervertebral discs and their relation to the low-back syndrome has accumulated. A brief review of some of the pertinent work follows.

Each intervertebral disc consists of three portions [2], the superior and inferior cartilaginous end-plates of the adjacent vertebrae, the annulus fibrosus consisting of concentric lamellae of fibro-elastic tissue, and the gelatinous central portion of the disc, the nucleus pulposus. The annulus fibrosus attaches above and below to the cartilaginous plate in its more central portions, to the bone of the peripheral portion of the end-plate at the site of the epiphyseal ring, and, at the extreme periphery, to the sides of the vertebral bodies. This peripheral portion fuses to and is inseparable from the anterior and posterior longitudinal ligaments. These ligaments are vertical bands of fibrous tissue which extend the length of the spinal column. The anterior ligament is of uniform width and is very strong, being firmly attached to the whole anterior surface of each vertebral body. The posterior ligament, on the other hand, has a scalloped appearance and is attached only to the discs and the superior and inferior margins of the vertebral bodies. Along the posterior surfaces of the vertebral bodies, it narrows to a thin strip with but a tenuous attachment to the posterior aspect of the centra (Fig. 18). Beneath this narrow portion are two foramina or vascular channels. Through these pass the major blood vessels which carry blood to and from the vascular spaces in the bone marrow of the vertebral bodies [16].

Anatomical studies have failed to demonstrate the presence of nerve fibers within the annulus or nucleus pulposus [31]. Hence it would seem unlikely that derangements within the disc could cause pain *per se*. Rather it would seem that the pain must originate in structures located in relation to the disc such as the bones, the posterior joints, the ligaments, the dura, and the spinal nerve-roots, all of which are known to contain nerve fibers capable of mediating pain sensation. However, there are clinical observations which suggest that in some cases the pain may originate within the disc.

Lindblom, Perey, and others have reported that the injection of saline solution or of some other solution into the appropriate disc space may reproduce the symptoms of some patients who are suffering from low-back and sciatic pain. However, if novocain is injected into these same discs, the pain is eliminated. Similarly Feffer has reported that the injection of the hormone, hydrocortisone, into the appropriate disc space has relieved symptoms in a substantial proportion of patients in whom rupture and actual protrusion or extrusion of a disc fragment had not occurred.

The intervertebral disc is an unique articular structure. Although relatively small in area (approximately two and one-quarter by one and one-quarter inches in the lumbar spine), a disc during life is subjected to all

* This research was performed by the Massachusetts Institute of Technology under a grant from the Donner Foundation, Inc., of Philadelphia, and by the Massachusetts General Hospital under research grant B-321(C) from the United States Public Health Service.

manner of stresses—often stresses of considerable magnitude. It has been estimated that the fourth lumbar intervertebral disc is subjected to a total load of approximately 1,500 pounds when a weight of 100 pounds is lifted with the trunk in the flexed position [21].

In relation to each intervertebral disc are two apophyseal joints which in combination with ligamentous structures are thought to limit the ranges and planes of motion which take place in the intervertebral disc.

These three articular structures (one disc and two apophyseal joints) which join adjacent vertebrae to one another are of necessity interrelated, abnormalities of any one of the three affecting the other two. However, the importance of this interrelationship in the causation of low-back pain has proved difficult to evaluate. Changes in all components of the intervertebral complex may be found at autopsy with no recorded history of back symptoms during the life of the patient. Furthermore, degenerative changes in the disc may reach a marked degree without correspondingly severe changes in the apophyseal joints and conversely [18, 19, 39].

Extensive pathological studies by Schmorl and others have described in detail the aging or degenerative changes which take place in the discs. These first appear in the second decade of life and increase in incidence and in degree in the ensuing decades. This early appearance of degenerative change is perhaps not too surprising in view of the fact that the disc has no direct blood supply in adult life [2] and the transfer of metabolites to and from these fibrocartilaginous structures must depend upon the diffusion of fluid across the cartilaginous plates and through the substance of the discs themselves. It is presumably for this reason also that the discs show no capacity for regeneration or repair except for some ingrowth of fibrous tissue as shown in the histological studies of many investigations [12].

The specific degenerative or aging changes which take place in the intervertebral discs involve the three component parts and the adjacent bone and articular structures. The nucleus pulposus loses its gelatinous quality through a gradual increase in collagen in the intercellular substance and through the associated decrease in water content [20]. Eventually more or less fragmentation of the nucleus takes place. In the annulus fibrosus circumferential and radial tears develop primarily in the parts which correspond to the concave sides of the habitual spinal curves. Hence in the lumbar region, these fissures tend to be posterior while in the thoracic region they are anterior [21].

The cartilaginous plates show aging changes which are characterized by the degeneration of the hyaline cartilage, the development of fissures and cracks, the ingrowth of fibrous tissue from the marrow spaces, and eventually the proliferation of the underlying bone [12].

These changes in the various components of the disc at first produce no structural change which can be visualized in the roentgenograms. However, as they progress, characteristic roentgenographic findings appear [4]. These include narrowing or decrease in the height of the disc space, proliferation and irregularity of outline of the bone underlying the cartilaginous plates, and the development of bone spurs in the region of attachment of the peripheral fibers of the annulus.

The effect of these changes upon the function of the intervertebral joints is not understood completely. However, in the earlier stages before changes can be seen on the roentgenograms, the following variations in behavior at an involved interspace have been found:

1. Abnormal movement of the superior vertebra on the one below was first visualized in living subjects by Knutsson by means of roentgenograms made in the lateral projection with the trunk in full flexion and in full extension. Similar abnormal motion has been found in association with disc degeneration in the lumbar interspaces in fresh autopsy material studied by Friberg and Hirsch and others.

2. Increased bulging of degenerated, softened discs, noted at operation by many observers, has been studied by Hirsch and Nachemson in autopsy material.

3. Rupture and protrusion of a portion of a degenerated disc with irritation of a spinal-nerve root has been found in many thousands of operations performed for the relief of low-back and sciatic pain.

In the later stages of the degenerative process mobility of the spine gradually decreases as the result of vertical narrowing of the interspaces, proliferation of fibrous tissue within these spaces, and the growth of bone spurs about the periphery of the annulus; these spurs may eventually become so large that they bridge and virtually immobilize the vertebrae. In view of these changes, it is of interest that studies [25] have indicated that the incidence of back pain and sciatica of the type under consideration here is greatest during middle life when the earlier stages of disc degeneration are most common, while in later life when the disc and the adjoining vertebrae tend to become stabilized, the frequency of back pain falls off.

Although chronic and recurrent low-back pain, with or without sciatic pain, may result from a variety of causes, the majority of patients seen with this syndrome have no specific roentgenographic or physical findings to explain their symptoms. It is tempting to assume that the early disc changes already described are the important etiological factors in the majority if not in all of these patients. However, the problem is not so simple.

Back pain is known to occur without demonstrable instability, and instability is occasionally seen in roentgenograms in the absence of back symptoms.

In autopsy material, Hirsch and Nachemson were unable to produce bulging of the discs during compression tests of a degree sufficient to cause nerve-root pressure.

Even concerning the well established entity of rupture of an intervertebral disc, there are many questions which cannot as yet be answered. For example, how significant is the mechanical derangement at a lumbar interspace from which a ruptured disc has been removed? There is a wide divergence of opinion on this point as evidenced by the lack of agreement concerning the need for spine fusion or stabilization of the spine after removal of the disc [26].

How does a protrusion or herniation move or change its shape during spinal movement? The evidence from myelography is conflicting [3, 5, 10, 28, 38] and of limited value since the changes in position and contour are visualized poorly by this technique.

Are the typical postures and the limitations of straight leg-raising found in patients with back trouble caused by the position of the involved nerve root relative to the disc protrusion [7], to tension in the nerve root [8], to movement of the root in contact with the disc [1, 6, 8], or to still other factors? [14] The operative findings and anatomical studies of various workers have not given entirely satisfactory answers to these questions.

Why is there frequently a delay between the precipitating trauma and the development of pain? Is it

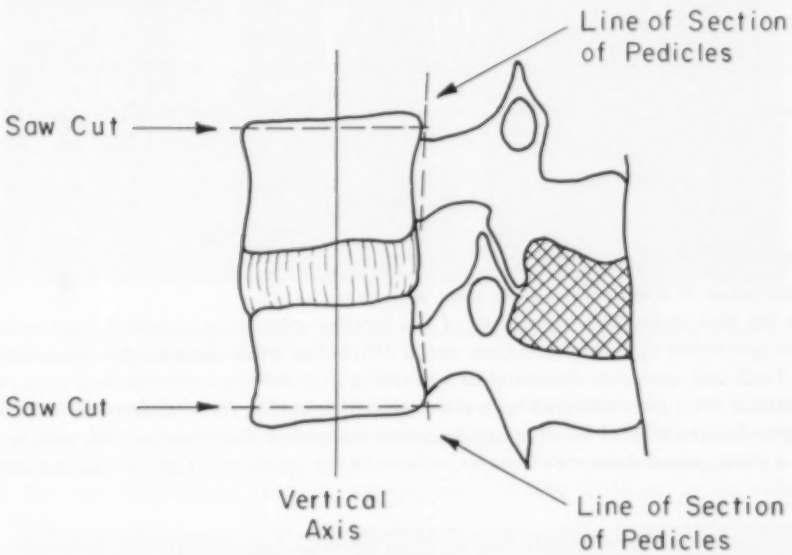


FIG. 1

Diagram illustrating how specimens were prepared for compression tests.

gradual extrusion of a loose fragment or swelling of the disc substance due to the imbibition of fluid by the disc ? [9] There is no direct evidence available to answer these questions.

It is thought that a more complete understanding of the mechanics of the spine will be necessary before such questions as these can be answered.

This preliminary report concerns a program of tests of the mechanical strength and elastic properties of the intervertebral discs, a joint effort of the Orthopaedic Service of the Massachusetts General Hospital and the Department of Civil and Sanitary Engineering of the Massachusetts Institute of Technology. The purpose of this investigation is to obtain quantitative data on the physical properties of the disc and related articular structures.

TEST TECHNIQUES

Although the lumbar intervertebral discs are obviously subjected to a variety of stress conditions during life, in the studies reported here only four basic types of mechanical tests have been performed with fresh specimens obtained from routine autopsies. These were: (1) axial compression tests, (2) tensile strength tests, (3) combined axial-load bending tests, and (4) fatigue tests.

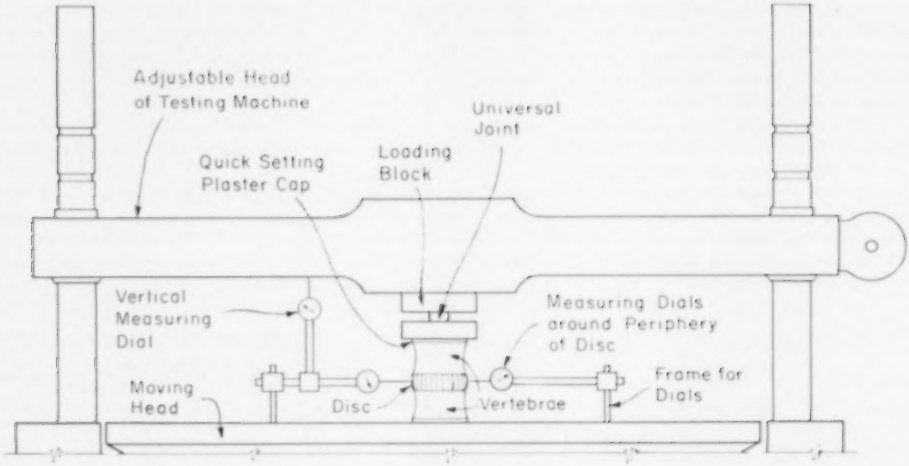


FIG. 2
Axial compression test.

1. *Compression Tests*

Two series of compression tests were performed:

In the first series fresh specimens of the lumbar spine were obtained from cadavera and test specimens were prepared from one or two of the lower three lumbar intervertebral joints. Each test specimen consisted of a vertebra-disc-vertebra combination from which the posterior bone elements had been removed by sectioning the pedicles and from which the exposed superior and inferior cartilaginous end-plates had been cut off with a band saw in a plane perpendicular to the vertical axis of the specimen (Fig. 1). The cut surfaces

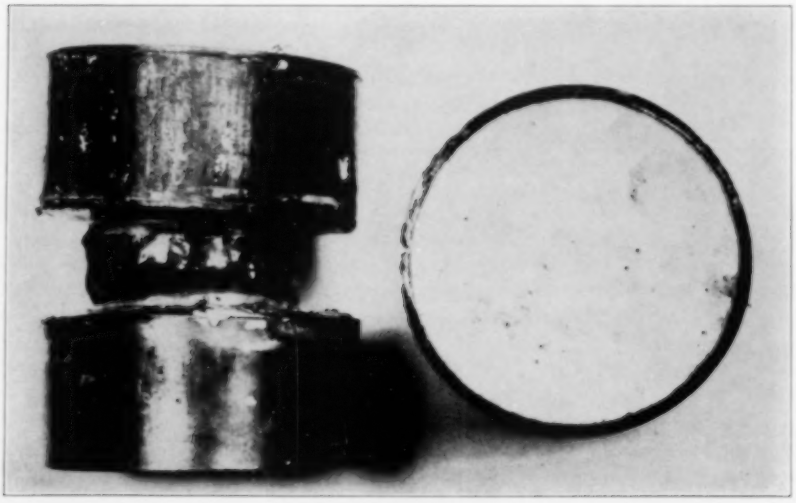


FIG. 3
Compression-test, volume-change specimen. Specimen is mounted in plaster contained within segments of copper pipe. Only the disc is exposed and it is coated with latex.

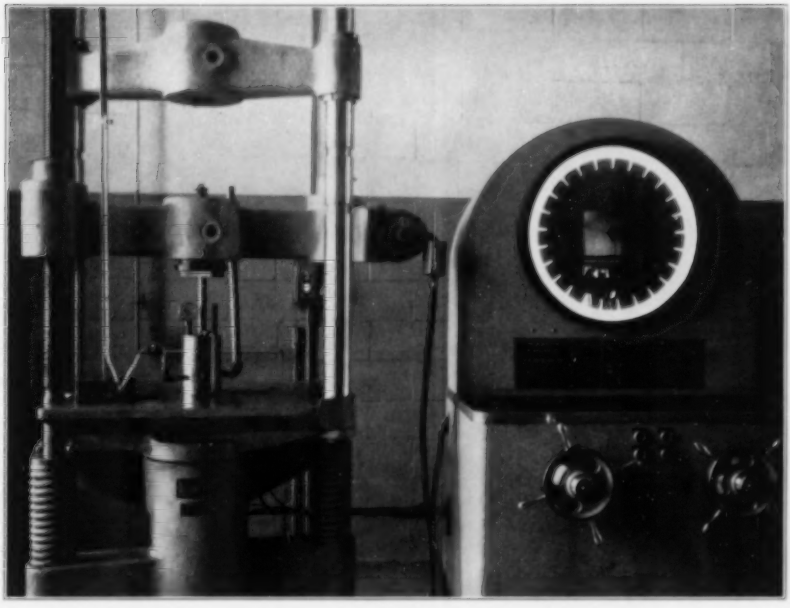


FIG. 4

Compression volume-change test. Cylinder with specimen is in place on the testing machine. Burette for recording volume change is on left.

of each specimen were capped with a quick-setting plaster. The specimens were then loaded to failure in a Baldwin-Tate-Emory hydraulic testing machine (Fig. 2). Measurements were made of the lateral expansions of each disc at several points about the circumference and of the axial deformation of each vertebra-disc-vertebra combination by means of Ames dials.

In the second series of compression tests, the objective was to determine the extent of the voids * within the disc and the extent of the flow of fluid through the cartilaginous end-plates of the vertebrae as the result of compression [27]. The specimens were prepared as were those in the first series of tests, except that each vertebra was embedded in plaster of Paris within a short section of pipe in such a fashion that only the disc was exposed. The entire specimen was then immersed in a liquid latex solution and allowed to dry, a thin elastic membrane being left which enclosed the disc (Fig. 3). This specimen was then placed upright in a cylinder filled with alcohol and fitted with a water-tight piston through which the load was applied by the testing machine (Fig. 4).

A burette graduated in 0.1 cubic centimeter was connected to the cylinder by means of a side tube. With this experimental set-up, if there were no voids to collapse and no fluid transfer from the disc to the medullary spaces to the vertebrae, the annulus would bulge laterally because of the axial load; and the calculated decrease in volume of the cylinder due to the descent of the piston and the actual change in volume as recorded by the displacement of the alcohol into the burette would be the same. On the other hand, if the calculated volume change were to exceed the actual volume change, then the volume of the disc must have decreased either from the collapse of voids within the disc substance or from the transfer of fluid from the disc into the vertebrae or from both of these mecha-

* In adult life the discs contain fissures and cracks which form spaces or voids which are either empty or more probably contain gas or fluid in the living state. When the spine is extended, these voids enlarge and sometimes can be visualized as radiolucent streaks in lateral roentgenograms, the so-called vacuum phenomenon [29].

nisms. Bending of the cartilaginous end-plates might also be responsible for some of the volume change, but roentgenograms of discs under axial load failed to show any evidence of significant deformation until failure occurred.

The plaster and copper pipe were of course relatively incompressible.

The volume change (the difference between the calculated and the actual cylinder volumes) and the vertical deflection of the specimen (descent of the piston) were measured as functions of the load and time.

The axial compressive load was arbitrarily applied in increments of fifty pounds for the first 300 pounds. At each level, the load was maintained for two minutes, and the volume change of the disc was measured at thirty-second intervals. After the compressive load had reached 300 pounds, the increment of load was increased to 100 pounds, and the readings of volume change made every fifteen seconds for a period of two minutes at each load level.

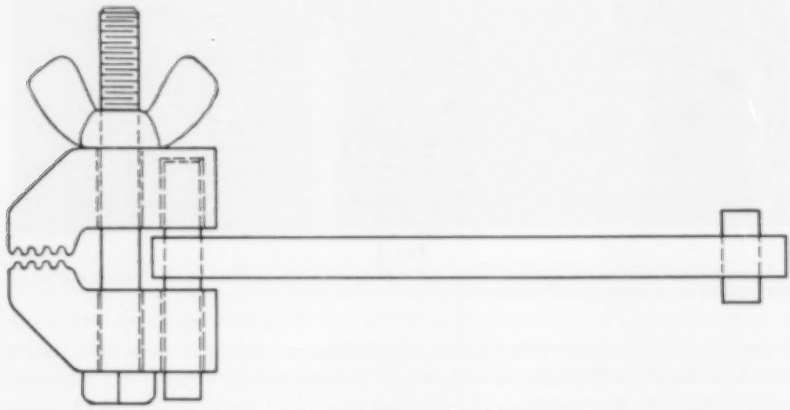


FIG. 5
Schematic drawing of clamps used in tensile tests.

At all load levels, there was some tendency for the load to decrease so that frequent adjustments of the testing machine were required in order to maintain a constant load for each two-minute interval. With increasing loads this tendency for the load to fall off increased until the point of failure when the load dropped sharply.

Removal of the posterior elements from the specimens before the compression tests were performed undoubtedly had some influence on the stresses developed within the disc during compression.

In the first place, in the intact spine the ligamentum flavum is under tension; its removal in the lumbar region results in slight widening of the disc space posteriorly so that the adjacent cartilaginous plates of the vertebrae tend to assume positions more nearly parallel to each other.

In the second place, although the disc under axial compression is, for all practical purposes, the sole weight-bearing element [49], the facet joints, because of their downward and backward inclination, must introduce other stresses such as shear in the disc during compression. Furthermore, with sufficient deformation of the disc, in at least some spines, the tips of the superior facets impinge against the pedicles of the vertebrae above and hence give some additional support to the posterior part of the disc.

For the purposes of these tests, however, it was deemed necessary to visualize the posterior aspect of the disc, to allow recording of the lateral expansion on the posterior aspect of the disc, and to reduce the experimental conditions to those of pure compression.

2. Tensile Tests

Degenerative changes in the intervertebral discs are characterized by the development of concentric and radial tears in the annulus fibrosus. These presumably result in a loss of strength of the annulus. An attempt was made to obtain some quantitative data on the tensile strength of various areas of the disc.

Test samples were obtained in the following manner. A fresh specimen consisting of two vertebrae and the connecting disc was removed at autopsy. The posterior articulations were cut off by section of the pedicles. Each vertebra was then cut with a band saw on a plane parallel to the cartilaginous plate nearest to the intact disc, leaving approximately one-eighth of an inch of bone attached to each surface of the disc. The disc with the attached plates of bone and cartilage was then cut with a band saw in the sagittal

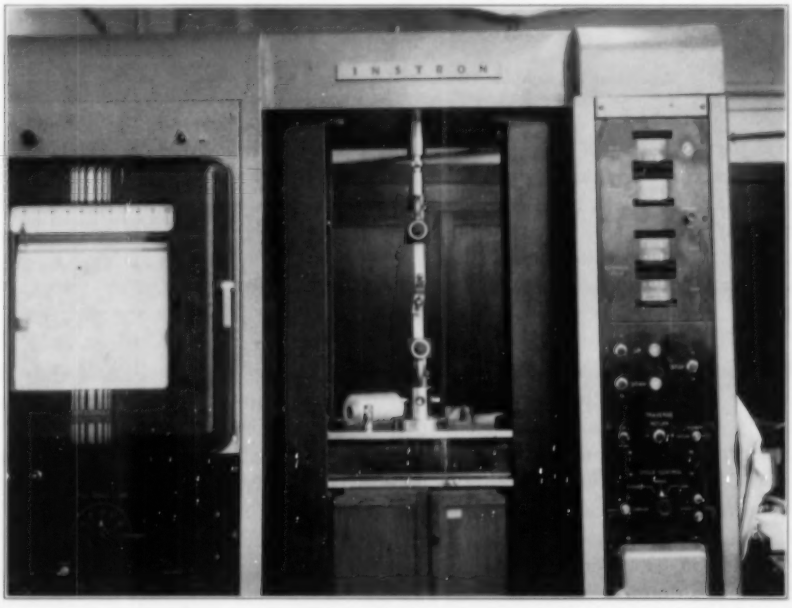


FIG. 6
Tension test. Specimen has started to fail on the right side causing the upper clamp to rotate.

plane in a serial fashion. The serial sections so obtained were approximately one-quarter of an inch in thickness and consisted of the disc and the attached bone plates. These sections were cut individually in the frontal plane by placing the cut surface on a board and by cutting serial sections with a sharp boning knife which was placed on the specimen in the proper position and struck with a mallet. This method proved simple and did not distort or tear the disc tissue between the two segments of bone.

Approximately twenty-five specimens were obtained from each disc with cross-sectional areas ranging from 0.024 to 0.25 square inch. The test specimens were identified by a coordinate system.

Various methods for gripping each specimen during testing were tried. Many of these were unsuccessful because of failure of the bone at the point of attachment of the annulus or slippage of the grips when these were applied to the disc tissue itself. Finally, two duraluminum clamps with interlocking blunt teeth were applied to the superior and inferior ends of each disc segment (Fig. 5).

Some of the disc segments were too weak to test because of partial ruptures of the

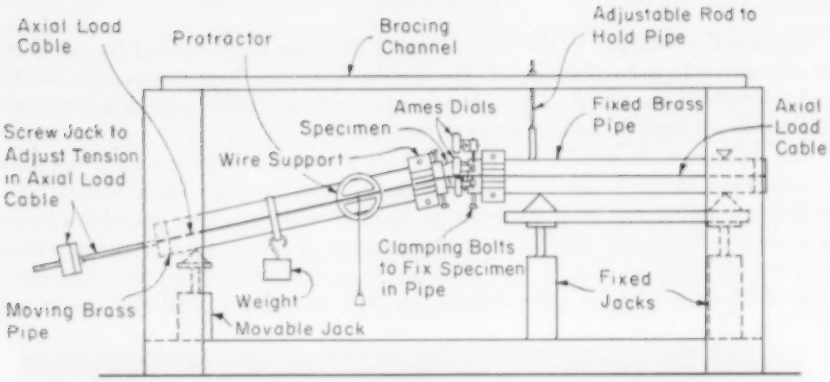


FIG. 7
Apparatus for combined axial load bending test (in rotated position).

annulus or because of detachments of the nucleus pulposus from the cartilaginous plates. This was true primarily in the more central portions of the disc. These ruptures and detachments appeared to be due to pre-existing degenerative changes and not to the method of sectioning. The specimens with their attached clamps were placed in an Instron textile testing machine (Fig. 6). This machine proved to be quite satisfactory because of its accuracy in the range below 100 pounds load. The load imposed on the specimen and the elongation of the specimen were recorded automatically.

3. *Combined Axial Load-Bending Test*

It is commonly assumed that axial stress on the spine is distributed uniformly through the nucleus pulposus to the cartilage plates and to the annulus and that the nucleus moves posteriorly during flexion, anteriorly during extension, and toward the convexity of the spinal curve during lateral bending. The articular facets and ligaments are thought to limit and track the motion occurring at each interspace [40], but there are no quantitative data concerning the influence of the ligaments and joints on the behavior of the disc.

In order to investigate the behavior of the discs during bending in various planes (such as flexion, extension, and lateral bending), the intervertebral joint between the fourth and fifth lumbar vertebrae from two specimens were subjected to combined axial compressive load and bending first with the facets, ligamentum flavum, and interspinous ligaments intact and then with these structures removed. Removal was accomplished with a Gigli saw which was passed through the intervertebral foramina from one side to the other. With this instrument portions of the laminae, the spinous processes of the adjacent vertebrae, and the facet joints were removed by making two oblique cuts from the foramen — one posteriorly and superiorly, the other posteriorly and inferiorly (Fig. 31).

Specimens were prepared in the following manner. All the lumbar vertebrae and the first sacral segment were removed at autopsy. The ends of each specimen were mounted in three-foot sections of brass pipe four inches in diameter, in such a fashion that only the intervertebral disc, the related posterior joints, and the spinous processes at the intervertebral joint to be tested were exposed (Fig. 7). The vertebral bodies were firmly clamped by means of eight bolts threaded through each pipe in a radial fashion. Further fixation was attained by filling each pipe with plaster of Paris. A constant axial compressive load of sixty pounds simulating the weight of the trunk was applied by means of the wire cable shown in Figure 7. Bending was induced by fixing one pipe in the horizontal position and allowing the other, suitably weighted, to drop gradually by lowering the supporting screw jack. By rotating the specimen with its attached pipes 45 degrees about its longi-

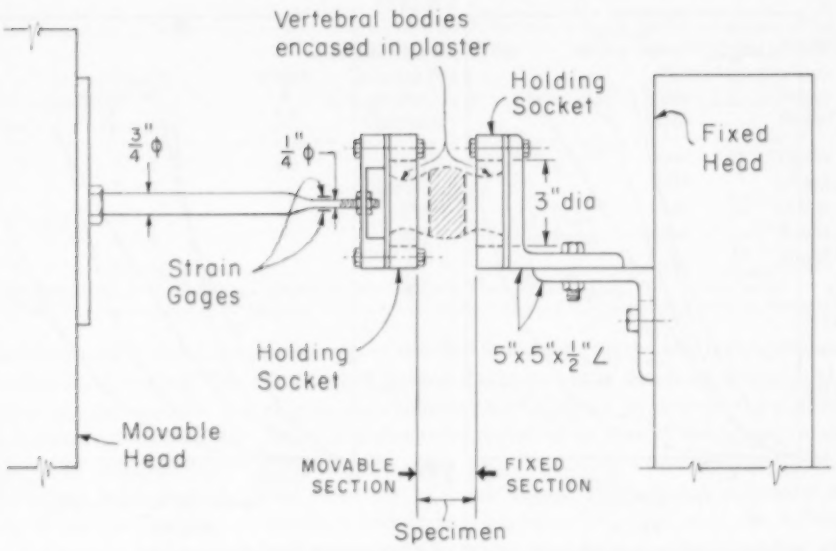


FIG. 8
Apparatus for fatigue test.

tudinal axis between each test, bending could be induced by the force of gravity along eight radii corresponding approximately to forward flexion, forward flexion to the right, lateral bending, backward bending to the right, backward bending, and so forth. Lateral deflections of the disc at various points about its periphery were recorded by measuring dials mounted on the stationary pipe.

4. *Fatigue Test*

Since the disc has a very limited capacity for regeneration and repair, it would appear that fatigue * must be an important factor in the development of the concentric and radial fissures in the annulus which are characteristic changes found in the early stages of degeneration.

An attempt was made to test fatigue in an intervertebral disc. Cyclic bending (5 degrees) and compression stresses (fifteen pounds) were imposed on a single disc, the posterior joints and ligamentous structures having been removed. The free ends of the specimen were embedded in plaster within holding sockets which were, in turn, bolted to the fatigue-testing machine. Figure 8 illustrates the mounting method used. The compressive stress was applied by the excursion of the movable head of the testing machine. Bending stress was achieved by adjusting the movable mounting block so that the thrust was sufficiently anterior to the mid-point of the specimen that 5 degrees of forward bending (rotation) at the disc occurred with each cycle.

The testing machine used would not permit operation at cyclic stress rate of less than 1,100 cycles per minute. The axial load, but not the bending moment, was measured as the test proceeded. Unfortunately the specimen failed so rapidly that it was not possible to obtain the bending moment which would be necessary to describe the test condition completely.

TEST RESULTS

Compression Tests

Five specimens, taken from three bodies, were subjected to pure compression tests.

* Fatigue in an engineering sense as used here refers to the failure of a material under cyclically repeated stresses at a stress level below that at which the material would fail if loaded only once.

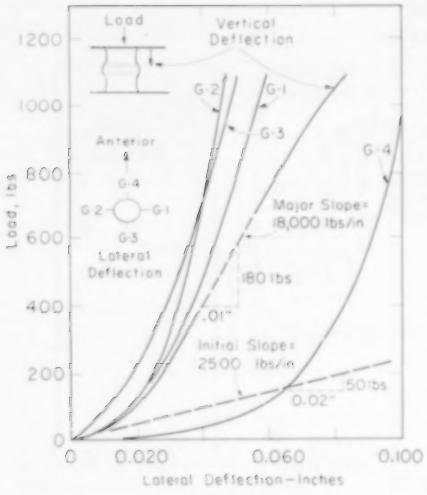


FIG. 9

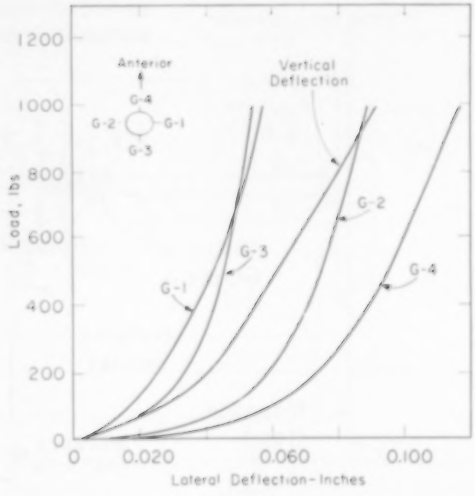


FIG. 10

Fig. 9: Lateral and vertical deflections due to axial compressive load. Test CAL 2-3.
Fig. 10: Lateral and vertical deflections due to axial compressive load. Test CAL 4-5.

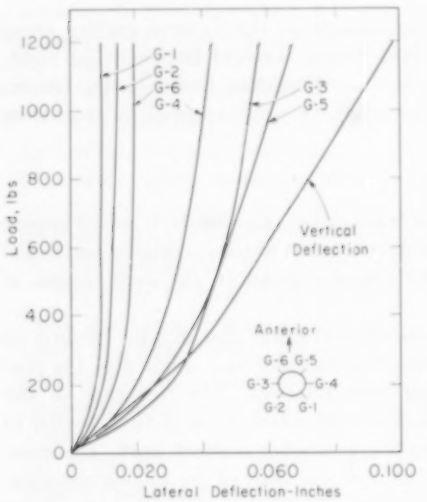


FIG. 11

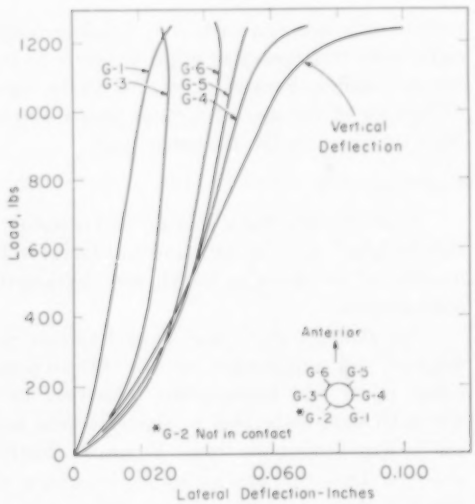


FIG. 12

Fig. 11: Lateral and vertical deflections due to axial compressive load. Test CBL 3-4.
Fig. 12: Lateral and vertical deflections due to axial compressive load. Test CBL 4-5.

The ultimate compressive load capacity and a measure of the stiffness under load of each of the discs tested is given in Table I. The method of determining the axial stiffness is indicated in Figure 9. All specimens failed in a similar manner characterized by a series of audible cracks followed by the leakage of sanguinous fluid from one of the vertebrae, usually the superior one. This leakage occurred for the most part through one or more of the vascular foramina but occasional minimal leakage also took place at some point along the attachment of peripheral fibers of the annulus to the sides of one of the vertebral bodies.

Inspection and palpation of these specimens after testing revealed surprisingly little

TABLE I

Specimen		Axial-Compression Tests	Axial Stiffness of Disc (*pounds per inch*)	
Body	Location	Ultimate Axial Compressive Load (*pounds*)	Initial Slope	Major Slope
A	L 2-3	1100	2500	18,000
	L 4-5	1000	3000	15,400
B	L 3-4	1200	7700	15,700
	L 5-S1	1250	8250	20,000
C	L 4-5	1300	470	12,000

The failure loads of all five specimens are seen to be in close agreement.

gross abnormality. Even the consistency of the disc in some instances was not significantly altered to hand testing. The condition of the cartilaginous plates was then determined by multiple sagittal sections of each specimen made with a band saw so as to produce slices of each vertebral body and the intervening disc one-quarter of an inch in thickness. In some instances no defect could be visualized. In other specimens close inspection and probing with a sharp instrument revealed small cracks in one of the cartilaginous end-plates and locally diminished rigidity of the plate and underlying bone. Fracture and local deformation of the plate had occurred with spontaneous return to a nearly normal position after removal of the load (Fig. 12).

Plots of the load as against lateral expansion and of the load as against axial distortion of each disc are given in Figures 9 through 13. All specimens behaved in a similar manner. As compressive load is applied, the disc compresses initially at a rapid rate (stiffness values of 475 to 8250 pounds per inch), but after the load reaches about 200 to 400 pounds, the rate of compression is greatly reduced (stiffness values of 12,000 to 20,000 pounds per inch). In spite of this qualitative similarity in behavior, it is evident that there are considerable quantitative differences in both the initial and in the major slopes of the vertical deflection curves of the various discs tested (Figs. 9 through 13).

It is also apparent that the lateral expansion of the discs in the areas tested varies considerably. In these few specimens it was not possible to correlate these differences in behavior with any observed structural changes in the annulus or in the nucleus pulposus. The curves plotted in Figure 12 indicate that this disc expanded in approximately the same fashion in all the areas tested (*G-1* to *G-6*). The curves for the other discs show more or less variation in their expansion, notably in Figure 9, where the anterior portion of the disc (*G-4*) expanded very differently from the other parts of this same disc.

In Figure 12 (*G-3* and *G-6*) and in Figure 13 (*G-6*), it appears that when these specimens started to fail, actual contraction in certain areas of the discs took place.

In order to visualize more clearly how failure occurred, four other specimens were subjected to pure compression in a portable press mounted on a turntable so that roentgenograms in the anteroposterior and lateral projections could be obtained. Roentgenograms were made before and during loading as well as after failure. Radiopaque fluid was injected into the disc before loading in one specimen and after failure in another. Roentgenograms were also obtained of bone-disc-bone slices which had been prepared with a band saw after completion of the compression tests.

The failure in the plate as visualized by this technique appeared to vary according to the condition of the vertebral body. The condition of the nucleus pulposus and of the annulus fibrosus did not seem to influence the manner in which failure occurred.

In the specimens showing osteoporosis rather extensive collapse of the plate and crumbling of the underlying bone trabeculae occurred at relatively small loads (Fig. 15), whereas in the specimens from younger individuals it was at times rather difficult to visualize the defect since only a small crack occurred with collapse of a few of the sup-

porting bone trabeculae. This was well shown in the roentgenograms of the bone-disc-bone slices (Fig. 16).

In the specimen in which a radiopaque solution was injected into the disc prior to loading, the roentgenograms reveal that before failure this solution remained in the voids within the disc, while after failure it had leaked into the vertebral body (Fig. 17).

With another specimen (Fig. 18) (the fourth and fifth lumbar disc from a female forty-five years old with an obvious protrusion in the mid-line posteriorly), loading to failure produced leakage of bloody fluid from the superior vertebra in a manner similar to that occurring in the other discs. Aside from the slight bulging at the site of protrusion during loading, no gross change was produced in the annulus as the result of the test. After failure, injection of radiopaque solution into the disc revealed leakage of the solution at the attachment of the annulus to the inferior vertebra on its posterior aspect just below the protrusion (Fig. 18). This rupture of the annulus had probably existed prior to testing since this was the site of the protrusion; leakage at this point is a common finding during clinical discography.

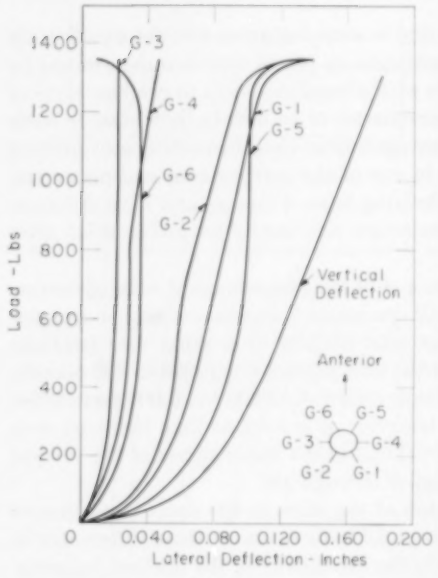


FIG. 13

Lateral and vertical deflections due to axial compressive load. Test CCL 4-5.

No leakage of the solution through either cartilage plate occurred in this specimen, but because of the rupture of the annulus no pressure could be developed within the disc. Subsequent roentgenograms of the bone-disc-bone slices did not reveal a visible crack (Fig. 22).

A back injury caused by lifting a heavy weight or by a fall in the sitting position might well produce damage to a vertebral body comparable to this. Were this the case, the lesion could obviously not be demonstrated by roentgenograms. It is conceivable that injuries to the vertebral body similar to the experimental ones might be one of the causes of low-back pain.

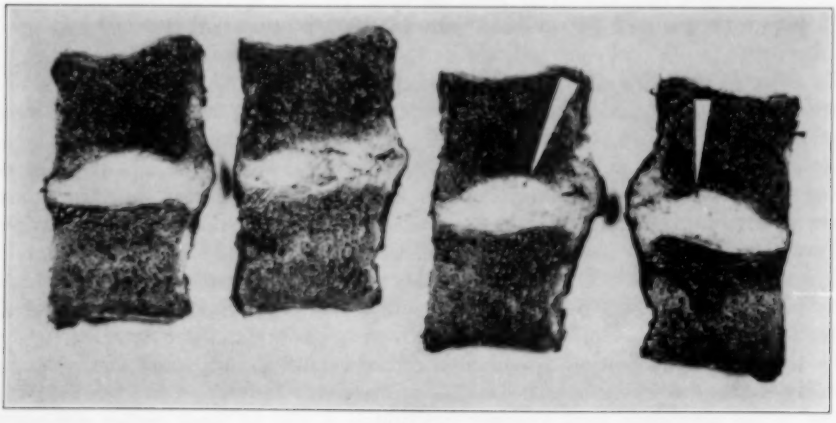


FIG. 14

Sagittal slices of vertebra-disc-vertebra specimen after axial loading to failure. Note degenerative changes in the disc in the two central sections and the failure in the plate indicated by the pointer.

Disc-Volume Change During Compression

Three specimens of the fourth and fifth lumbar intervertebral disc and two of the second and third lumbar intervertebral disc were obtained from three autopsies. These were subjected to pure compression, and recordings were made of the vertical compression

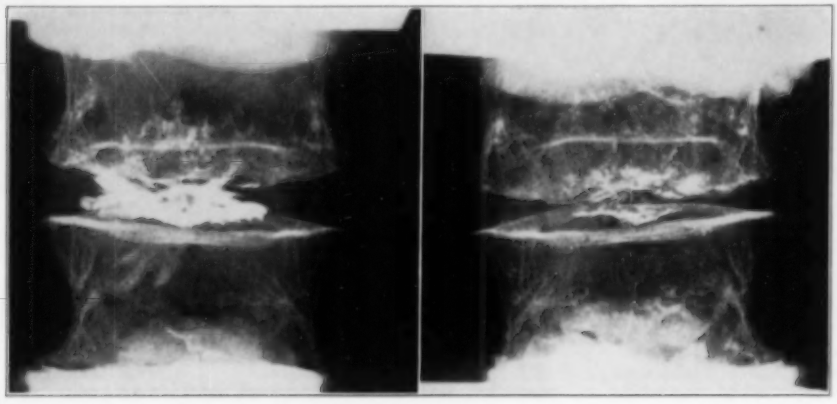


FIG. 15

Osteoporotic spine with disc space injected with diodrast, before (left) and after (right) loading to failure. Note upward displacement of the whole central portion of the plate of the upper vertebra and dispersion of diodrast into the vertebral body.

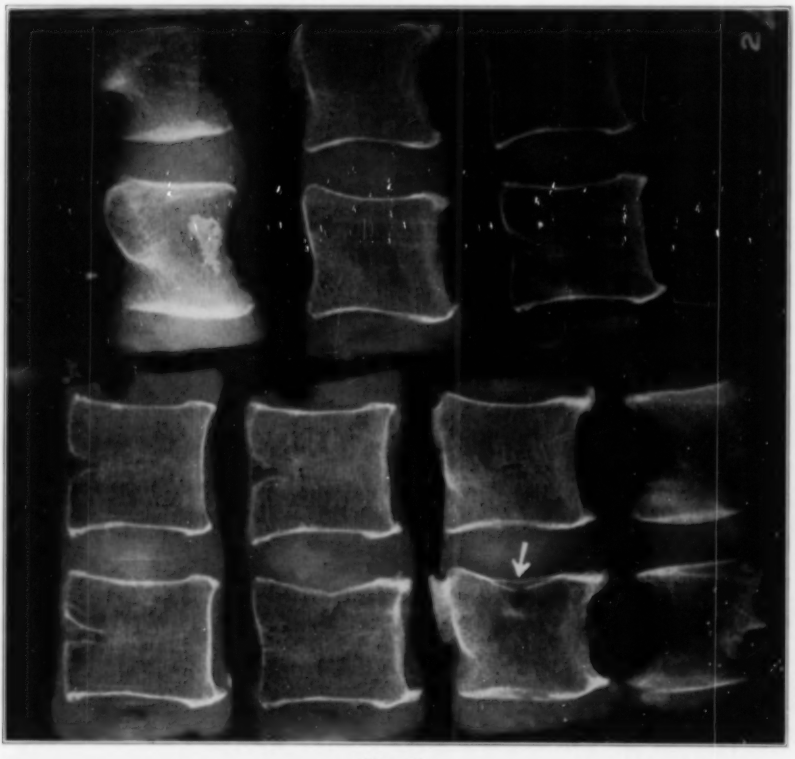


FIG. 16

Roentgenogram of vertebra-disc-vertebra slices from a specimen after failure. Note localized collapse of the plate of the lower vertebra (arrow).

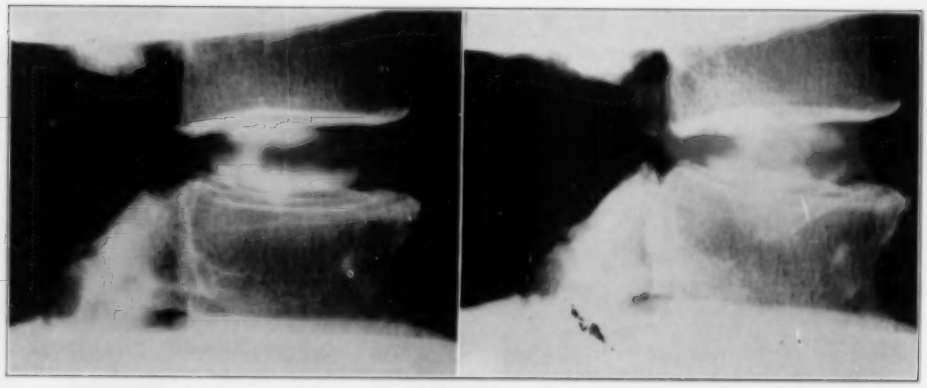


FIG. 17

Lateral view of disc space injected with 35 per cent diodrast before (left) and after (right) failure under axial compressive load. Roentgenogram on right was made while load was still applied. Note collapse of lower plate and leakage of diodrast into bone.

and of the volume change of the disc according to the method previously described. Since these specimens were loaded while contained in a steel cylinder filled with alcohol, failure could not be visualized directly. However, failure was presumed to occur at the load at which the rate of vertical deflection began to increase rapidly. The failure loads were therefore 1,100, 1,000, 300, 300, and 500 pounds, respectively (Figs. 23 through 27). The vertebral bodies of the three specimens which failed at 500 pounds or less were osteoporotic. This would account for these relatively low ultimate axial compressive loads (see Table I).

FIG. 18

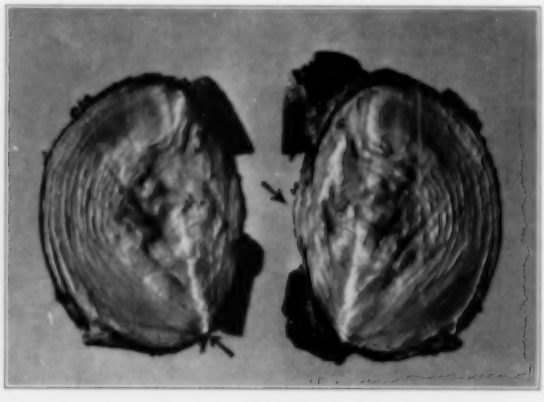


FIG. 19

Fig. 18: Segment of lumbar spine viewed from behind after removal of posterior elements by section of the pedicles. Note central protrusion at fourth and fifth lumbar interspace (pointer).

Fig. 19: Section through fourth and fifth lumbar disc shown in Fig. 18 made after failure due to axial compressive load (see Figs. 20 and 21). Note that the anterior annulus is thick and grossly normal. Bilateral radial posterolateral ruptures of the annulus can be seen (arrows) with resultant protrusion of the central posterior portion of the annulus and the posterior portion of the nucleus pulposus. Formalin fixation has produced some shrinkage.

In each case, the volume of the disc decreased as the load increased. However, after a certain level of load was reached, a somewhat anomalous behavior was observed, for the absolute volume of the disc suddenly increased to a value consistent with a much lower compressive load in two specimens, while in the remaining three specimens the volume

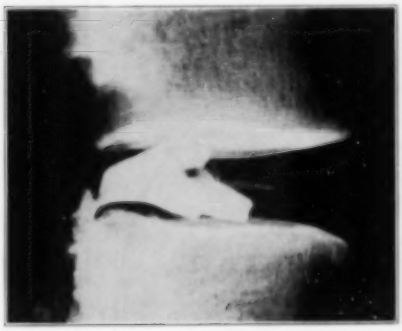


FIG. 20

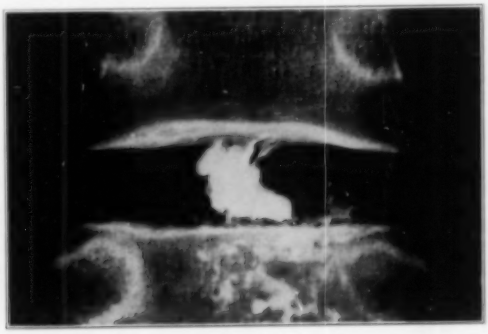


FIG. 21

Fig. 20: Lateral view of the fourth and fifth lumbar disc injected with pantopaque after failure under axial compression. Note leakage posteriorly beneath protrusion (some dye can be seen in the injection tract anteriorly). No deformation of either plate can be seen.

Fig. 21: Anteroposterior view of the fourth and fifth lumbar disc shown in Fig. 18. This roentgenogram and the lateral view shown in Fig. 20 were both made after the specimen had failed under axial compression and the disc had subsequently been injected with pantopaque. No deformation of the end-plates or of the underlying bone trabeculae is visible even though the superior plate presumably did fail since the characteristic leakage of bloody fluid from the upper vertebra was observed at the time of failure. The pantopaque fills the degenerated posterior portion of the disc and leaks out through the posterior rupture. It does not leak through either end-plate into the adjacent vertebral bodies. The degenerative changes in this disc are localized to its posterior portion as shown by the dispersion of the dye and also by the cut section of this disc shown in Fig. 19.

FIG. 22

Roentgenogram of sagittal sections of the fourth and fifth lumbar disc shown in Figs. 18 to 21 after formalin fixation and horizontal section through the disc. No evidence of plate fracture is visualized. None could be demonstrated on examination. Separated disc fragment in central posterior protrusion is well seen (lower left). Shrinkage of disc tissue has occurred due to formalin fixation.

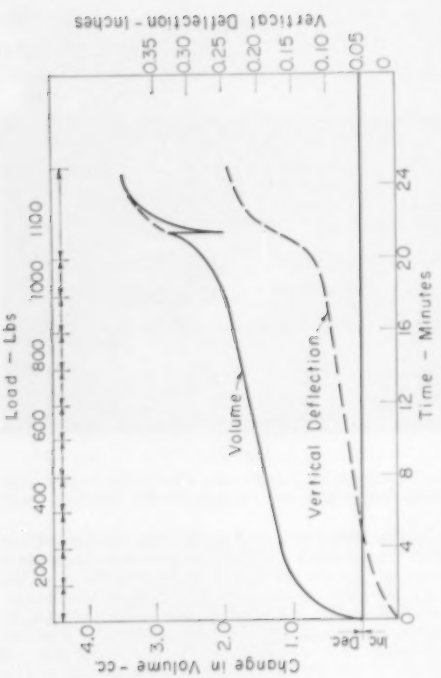


Fig. 24

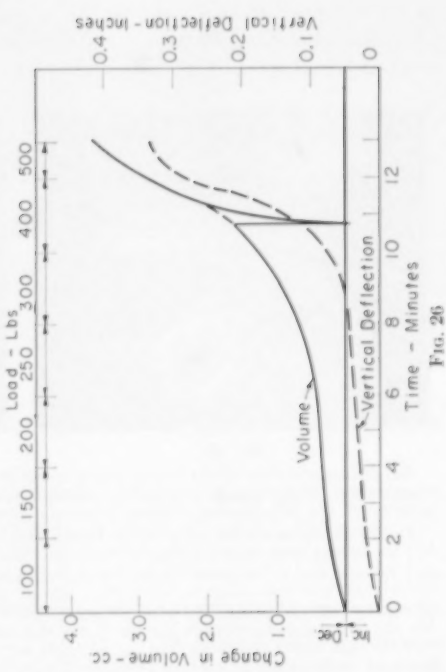


Fig. 26

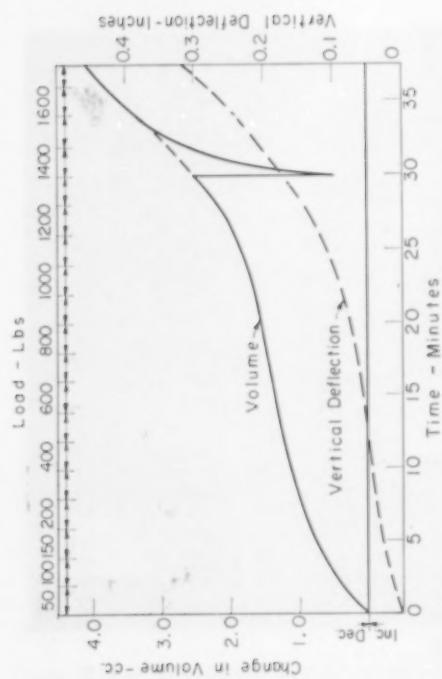


Fig. 23

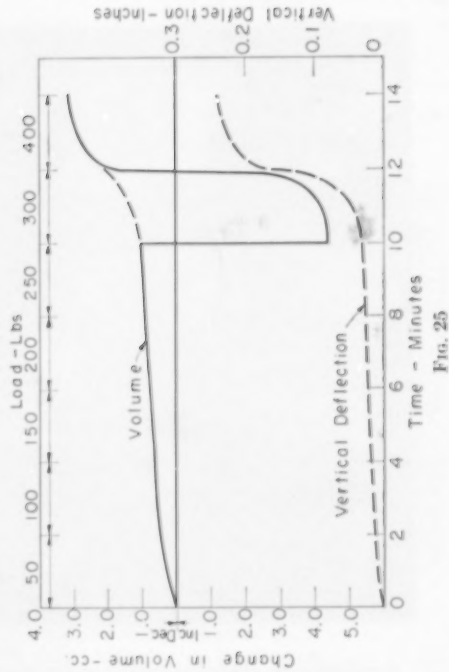


Fig. 25

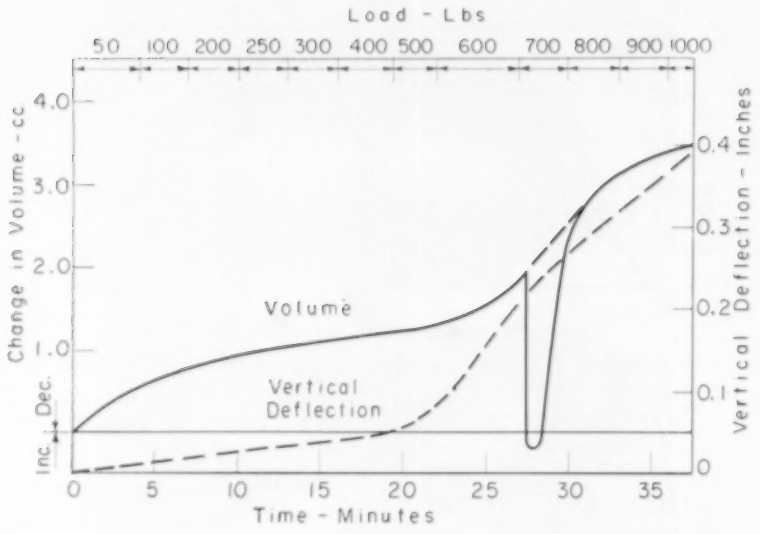


FIG. 27

Vertical deflection and volumetric change due to axial compressive load for denoted time intervals. Test VC 4-5.

actually increased momentarily over that present before any load was applied. Thereafter in all these specimens (as the time increased or as the next load increment was applied), the absolute volume of the disc approached a value consistent with that prior to the anomalous behavior.

The time relationship of this anomalous behavior to failure was variable. In most specimens an increase in the rate of vertical deflection characteristic of failure preceded the increase in volume. However, in one specimen (Fig. 25) the two occurred simultaneously. Examination of the specimens after removal from the cylinder revealed cracks in the vertebral plates and actual displacement of the vertebral plates into the vertebral bodies in the more osteoporotic specimens caused by the crushing of the underlying cancellous bone. The disruption of the specimens in these tests was considerably more marked than that found in the specimens used in the previous pure compression tests because increasing loads were applied after initial failure. Under the conditions of these tests, it was, therefore, impossible to visualize what structural changes had occurred at the time of the anomalous behavior.

Several explanations for the strange volume change have been advanced but none can be substantiated. The most reasonable explanation is that the initial relatively rapid decrease in volume results from compression of the disc and, to a much lesser extent, of the bone which occurs as the volume of the voids present in these structures is reduced to zero. The subsequent gradual and relatively constant rate of decrease in volume results from the passage of fluid across the cartilaginous plates from the disc to the marrow spaces within the vertebral bodies. When the specimen begins to fail or collapse as manifested by the rapid increase in vertical deflection, there is a sudden apparent increase in disc

Fig. 23: Vertical deflection and volumetric change due to axial compressive load for denoted time intervals. Test VA 2-3.

Fig. 24: Vertical deflection and volumetric change due to axial compressive load for denoted time intervals. Test VA 4-5.

Fig. 25: Vertical deflection and volumetric change due to axial compressive load for denoted time intervals. Test VB 2-3.

Fig. 26: Vertical deflection and volumetric change due to axial compressive load for denoted time intervals. Test VB 4-5.

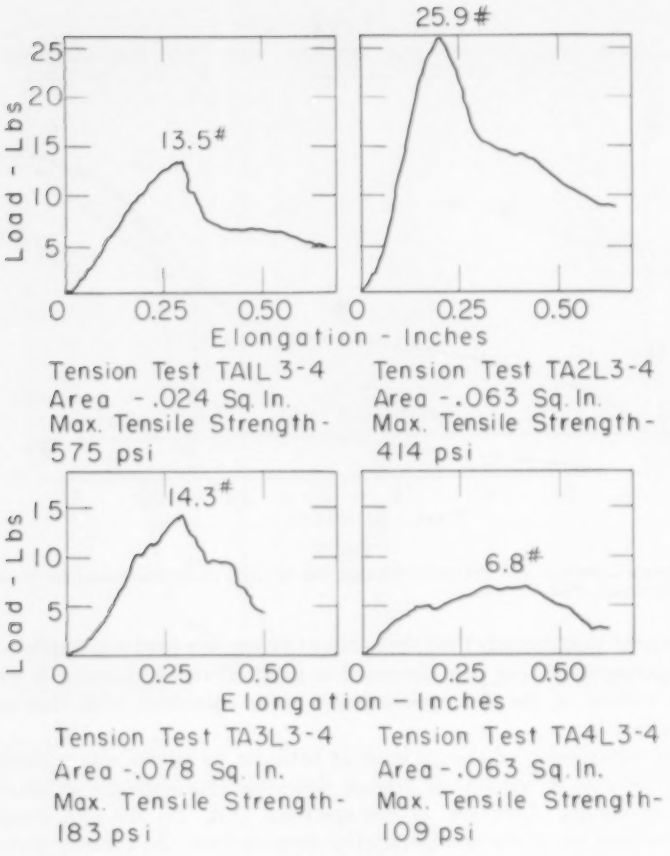


FIG. 28

Typical recordings in tension test. Specimen TL 3-4.

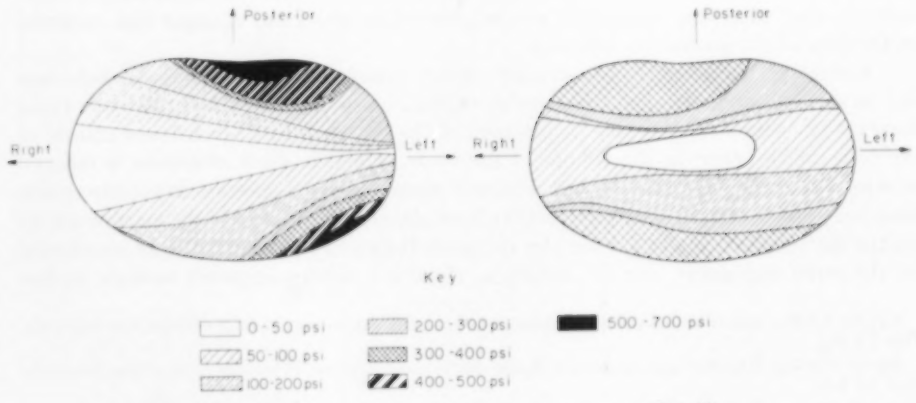


FIG. 29

FIG. 30

Fig. 29: Maximum tensile strength contours of intervertebral disc. Test TL 3-4.
Fig. 30: Maximum tensile strength contours of intervertebral disc. Test TL 4-5.

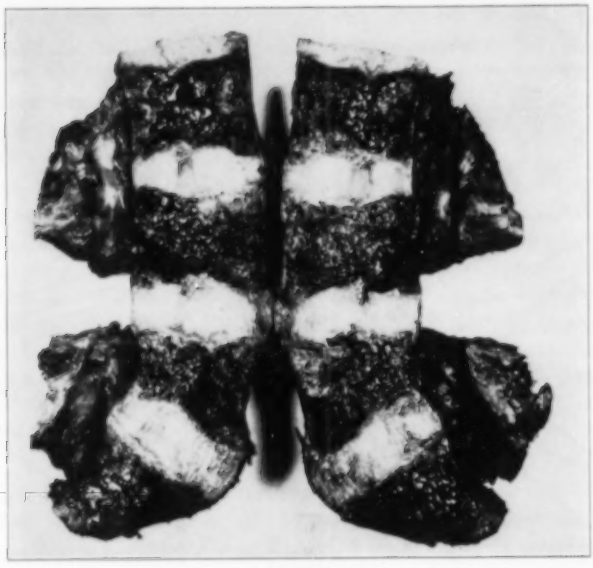
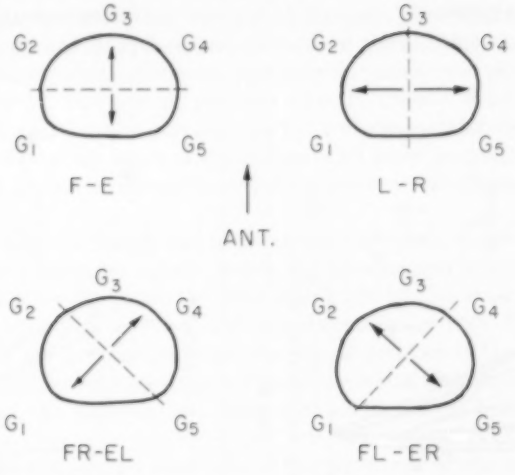


FIG. 31

Hyperflexion after removal of the posterior elements produced failure of the fourth lumbar vertebra.



G1-G5 = Positions Of Five Ames Dials About Circumference Of The Annulus

← → = Plane And Direction Of Movement Or Rotation

– – – – = Axis Of Rotation

F-E = Flexion-Extension (Backward And Forward Bending)

L-R = Left-Right Side Bending

FR-EL = Forward Bending To Right - Backward Bending To Left

FL-ER = Forward Bending To Left - Backward Bending To Right

FIG. 32

Schematic drawing showing axes and planes of motion in the disc in combined axial-load bending test. Specimen is viewed from above.

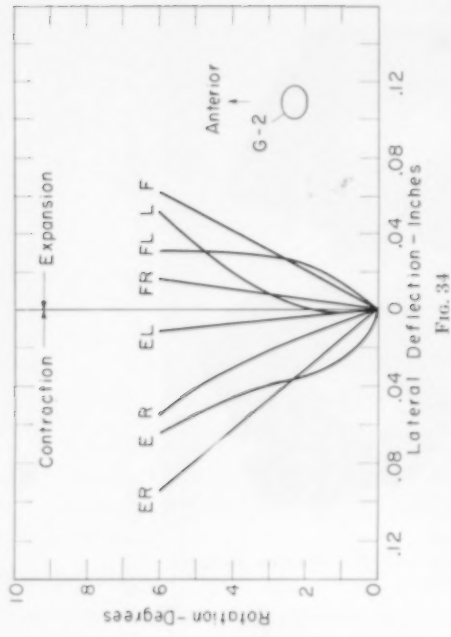


FIG. 34

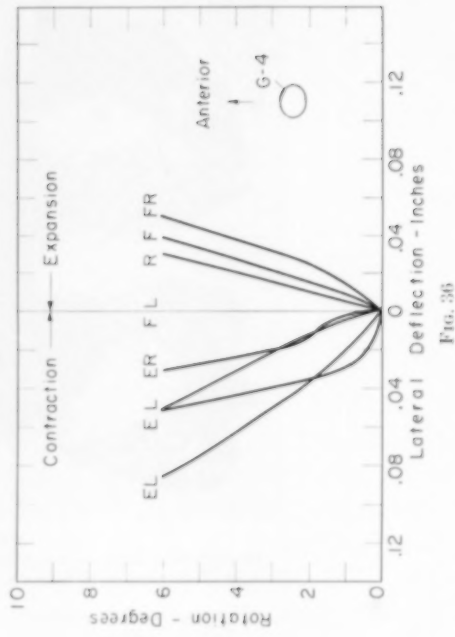


FIG. 36

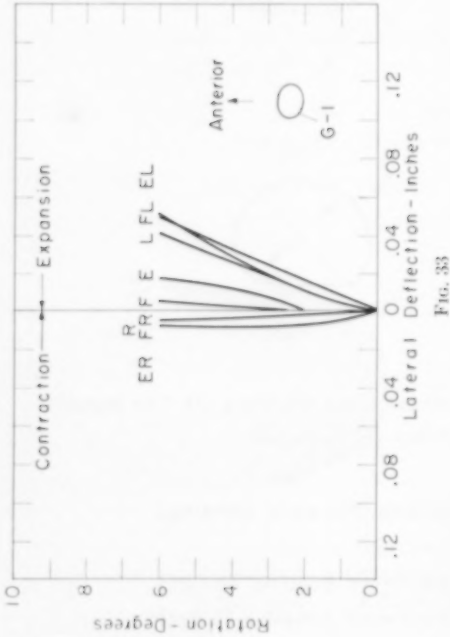


FIG. 33

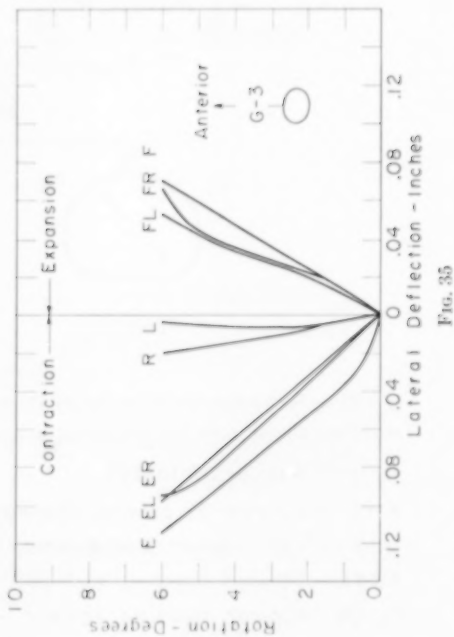


FIG. 35

volume. Since failure in the other experiments was characterized by the leakage of fluid from the bone, it seems quite probable that here also there is leakage of fluid which balloons out the latex film, producing an apparent transitory increase in volume of the disc which subsequently disappears as the bone trabeculae beneath the fractured plate crumble. The decrease in volume of the disc resumes its approximate former rate as the spongy bone of the vertebral body continues to collapse.

Another explanation could be that as the compressive load is increased, both disc and vertebrae are compressed, thereby reducing the volume of the voids to zero and gradually increasing the fluid pressure in both disc and vertebrae. At some load level, the pressure of fluid in the vertebrae becomes greater than that in the disc and failure occurs in the plate, separating the fluid in the disc from that in the vertebra. The fluid in the superior vertebra, being under higher pressure than that in the disc, then flows to the disc and causes a lateral distention of the disc, momentarily increasing its volume. However, as vertical compression continues, the volume is further decreased until it approaches values consistent with the earlier behavior.

Tension Tests

Two discs from the same spine were tested, the first being the one between the third and fourth lumbar vertebrae and the second being the one between the fourth and fifth lumbar vertebrae. These specimens were obtained from the cadaver of a patient in the sixth decade of life. The intervertebral discs tested showed no gross degenerative changes externally.

The results of the tensile tests were plotted as load deflection curves (Fig. 28)—each curve representing the results for one segment of the disc. The segments of the disc were taken from both the peripheral and central portions of the annulus and from the nucleus pulposus. As might be expected, there was considerable variation in the ultimate strength of these test specimens. The central portions were in general much weaker than the peripheral, while the anterior and posterior portions of the annulus were stronger, being fused with and re-enforced by fibers of the anterior and posterior longitudinal ligaments, respectively. Figures 29 and 30 present a plot of the contours of ultimate strength for the two discs tested.

In the disc between the fourth and fifth lumbar vertebrae, the strength varied from less than fifty to 400 pounds per square inch in the anterior and posterior sections of the annulus, while in the other disc, from the third and fourth lumbar interspace, the strength of the annulus rose to as high as 400 to 700 pounds per square inch. It can be seen that, with the exception of the nucleus pulposus, the lateral portions of the annulus possessed the least tensile strength in both specimens. This is consistent with the observed frequency of spur formation on the anterolateral aspects of the vertebral bodies in pathological material [2].

In Figure 29 the widespread weakness of the right side of the annulus in the disc between the third and fourth lumbar vertebrae is apparent. It might be anticipated that such asymmetrical weakness would be associated with some structural change visible in the specimen. For example, with a lateral curvature, degeneration of the annulus is known to occur on the concave side [37]. Again vertebral spurs forming at the site of attachment of the anterior longitudinal ligament and of the peripheral annulus fibers to the vertebral

Fig. 33: Lateral deflections at the left rear of the intervertebral disc caused by bending (rotation) in various planes. Specimen intact. Test BA 4-5 (see Fig. 32).

Fig. 34: Lateral deflections at the left front of the intervertebral disc caused by bending (rotation) in various planes. Specimen intact. Test BA 4-5 (see Fig. 32).

Fig. 35: Lateral deflections at the front of the intervertebral disc caused by bending (rotation) in various planes. Specimen intact. Test BA 4-5 (see Fig. 32).

Fig. 36: Lateral deflections at the right front of the intervertebral disc caused by bending (rotation) in various planes. Specimen intact. Test BA 4-5 (see Fig. 32).

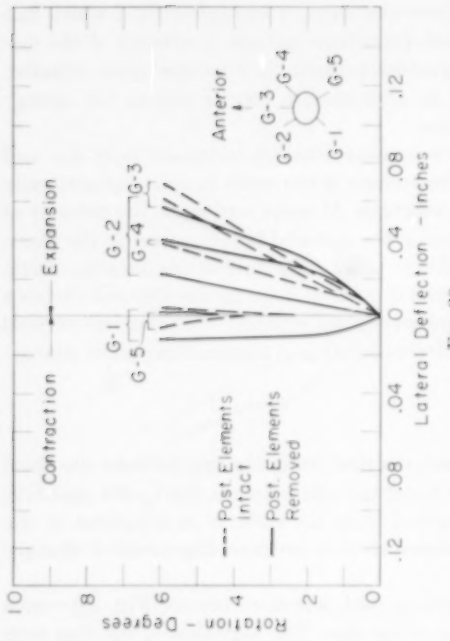


FIG. 38

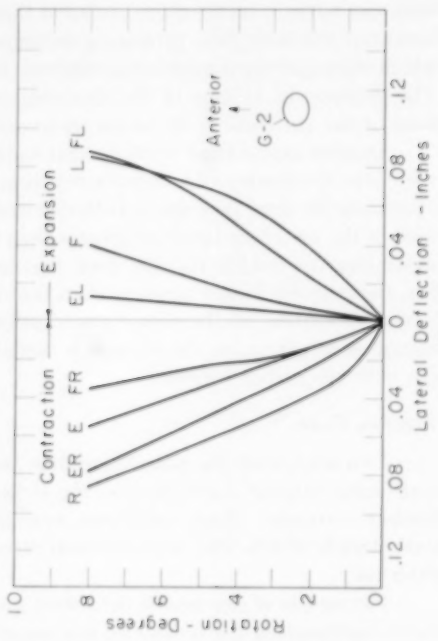


FIG. 40

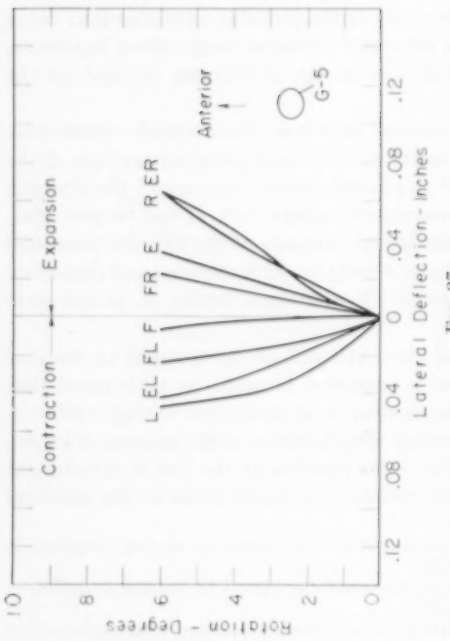


FIG. 37

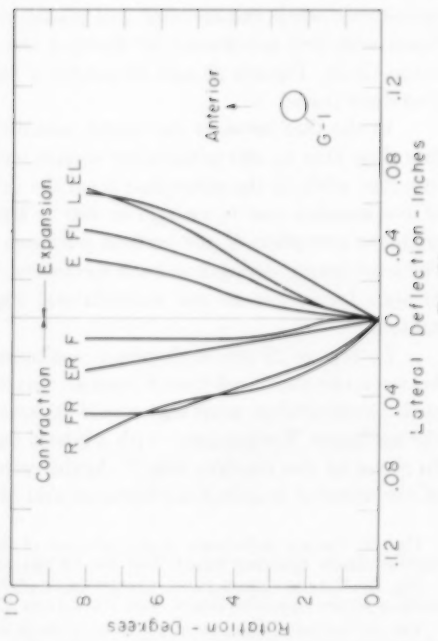


FIG. 39

bodies are thought to result from abnormal tension on these outer fibers caused by associated disc degeneration [2]. Neither a curvature nor spurs were present in this specimen.

In addition to tensile tests on the disc proper, three specimens of the ligamentum flavum from the fourth and fifth lumbar interspace were also tested. Maximum tensile strength of this tissue ranged from 226 to 373 pounds per square inch. The tensile strength of the ligamentum flavum was, therefore, of the same order of magnitude as that found in most of the annulus.

Combined Axial-Load Bending Tests

Specimens of the lumbosacral spine were obtained at autopsy from the cadavera of two patients who died in the sixth decade of life.

After mounting in the apparatus previously described, the lateral deformations of the disc between the fourth and fifth lumbar vertebrae were determined at five points (*G-1* to *G-5*, Fig. 38) about the periphery of the annulus while a constant axial load of sixty pounds was applied and bending was induced in various planes. In each specimen the starting or zero point corresponded to the relative position assumed spontaneously by the vertebrae contiguous to the interspace after the removal of the specimen from the body. Angulation amounting to 6 degrees in one specimen and to 8 degrees in the other was induced in the following directions: flexion, extension, right and left side bending, and forward and backward bending in planes lying at 45 degrees to the sagittal plane. In other words, bending through an arc of 6 degrees and 8 degrees respectively was produced along eight radii at 45 degrees to each other. This was equivalent to backward and forward motion of 12 and 16 degrees, respectively, along four planes (or diameters) corresponding to flexion and extension, right and left side bending, and forward and backward bending in the two oblique planes.

The axial load under the conditions of these tests was far below the ultimate strength of similar specimens subjected to the previously described compression tests (Table I).

This load was also less than that borne normally by the lower lumbar intervertebral discs during simple forward bending from the erect position. Hoag and Rosenberg estimated that the load on the disc between the fourth and fifth lumbar vertebrae during simple forward bending is about 400 pounds.

Similarly this amount of motion was considerably less than that necessary to produce failure experimentally. In one of the specimens at the completion of the tests and after removal of the posterior elements, that is, the posterior joints and ligamentum flavum, failure was induced by forward flexion of approximately 15 degrees from the neutral position. Failure occurred in the superior vertebra when a triangular fragment of bone was avulsed from its postero-inferior aspect (Fig. 31).

On the other hand, the amount of motion produced at these interspaces experimentally was probably in excess of that normally occurring during life. Roentgenographic studies by Tanz on living subjects revealed that the to-and-fro motion, from full flexion to full extension, at the fourth and fifth lumbar interspace showed considerable individual variation and a definite decrease in the older age groups. The mean for patients of fifty to sixty-four years of age was 8 degrees (range, 3 to 16 degrees). In the specimens tested the to-and-fro motion from extension to flexion was 12 and 16 degrees, respectively. This was considerably in excess of the mean but still within the range of observed motion at this interspace during life.

Fig. 37: Lateral deflections at the right rear of the intervertebral disc caused by bending (rotation) in various planes. Specimen intact. Test BA 4-5 (see Fig. 32).

Fig. 38: Comparison of lateral deflections of the disc during forward bending before and after removal of the posterior elements. Test BA 4-5 (see Fig. 32).

Fig. 39: Lateral deflection at the left rear of the intervertebral disc caused by bending (rotation) in various planes. Specimen intact. Test BB 4-5 (see Fig. 32).

Fig. 40: Lateral deflections at the left front of the intervertebral disc caused by bending (rotation) in various planes. Specimen intact. Test BB 4-5 (see Fig. 32).

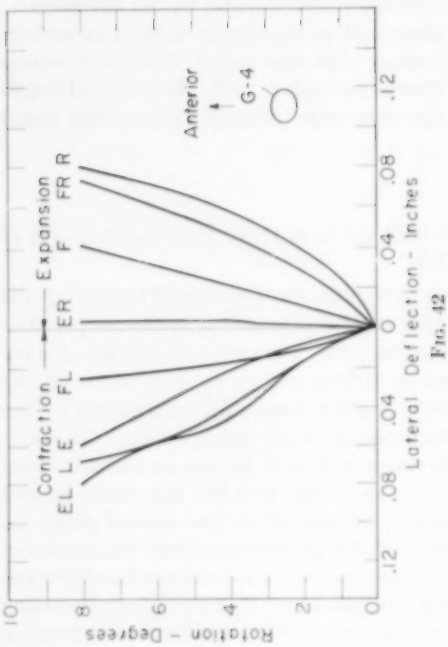


Fig. 42

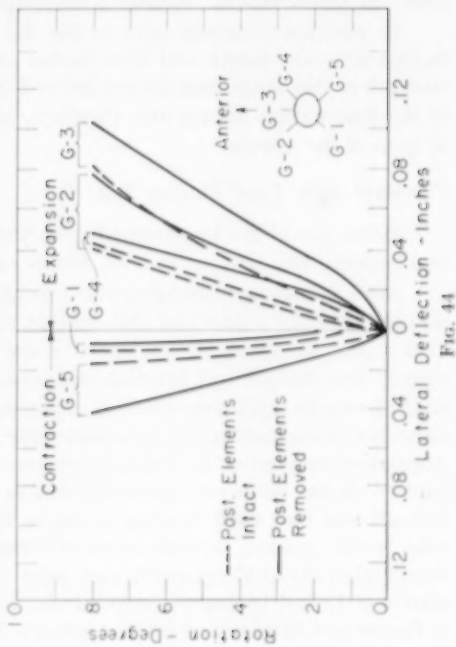


Fig. 44

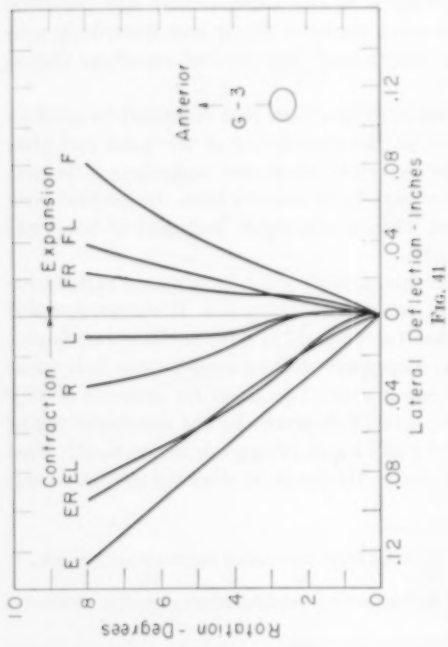


Fig. 41

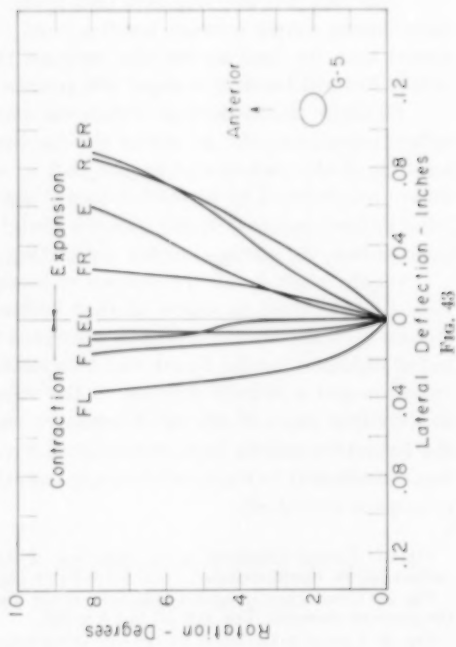


Fig. 43

The movements at the two interspaces studied in this experiment, although not ordinarily considered by clinicians to represent rotation, are in fact rotation of the moving vertebra about an axis located somewhere within the disc in the region of the nucleus pulposus [19]. With this experimental setup, it was possible to record the expansion and contraction of the annulus both in the plane and in the approximate axis of this rotation (Fig. 32).

Although the data obtained are not complete, they do give some indication of the behavior of the annulus during all major spinal movements except for axial rotation.

From Figures 33 through 37 and 39 through 43, it is evident that under these experimental conditions the discs expanded on the side toward which rotation took place and contracted on the opposite side. In contrast to this, those portions of the disc lying in the axis of rotation (that is at 90 degrees to the plane of rotation) showed relatively little change during to-and-fro movement. This is shown most clearly in Figures 35 and 41. Here the anterior part of the annulus (*G-3*) showed a marked degree of expansion and contraction during flexion (*F*) and extension (*E*) when it was in the plane of rotation. On the other hand, it moved relatively little during right (*R*) and left (*L*) lateral bending when it was in the axis of rotation. During movements in the two oblique planes (*FL-ER* and *FR-EL*), all combining flexion and extension with side bending, expansion and contraction at the anterior part of the annulus (*G-3*) occurred but to a lesser degree.

The most marked expansion and contraction in both specimens occurred on the anterior aspect of the annulus (*G-3* in Figs. 35 and 41) during flexion and extension. It is of interest that this portion of the annulus, which is the thickest portion and which is reinforced by the anterior longitudinal ligament, should show the greatest excursion.

In both discs, the occurrence of expansion and contraction of the annulus, as recorded at the five points tested, was quite consistent. The only exceptions to this are noted in the posterolateral dials at *G-1* and *G-5*. For example, in Figure 33 minimal motion would be expected at *G-1* during forward bending to the left (*FL*) and backward bending to the right (*ER*) since during these movements, *G-1* would be in the approximate axis of rotation; this, however, was not the case. Similar anomalous behavior is shown in Figure 37 at *G-5*, a comparable point on the other side of this same disc, and in Figure 39 showing the findings at *G-1* on the other specimen. In this other specimen, however, no such anomalous behavior occurred on the posterolateral aspect on the opposite side (*G-5*).

From the data available it is not possible to correlate these findings with abnormalities in the discs at these locations. However, it is of interest that the pathological studies of Friberg and Hirsch demonstrated that annular ruptures occur frequently in the posterolateral portions of the annulus in the lower lumbar interspaces (Fig. 17). It is unfortunate that under these experimental conditions it was impossible to record the behavior of the posterior aspect of the annulus and the posterior longitudinal ligament with the laminae and flaval ligaments intact.

It is of some interest to compare the expansion of these discs, which were subjected to combined bending and a light axial load, to the expansion produced in the discs which were subjected to pure axial compression until failure (Figs. 9 through 13). Although there is wide individual variation, it would appear that the combined axial-load bending test, even though terminated well below failure, produced more expansion anteriorly and posterolaterally than axial compression even at the point of failure.

Fig. 41: Lateral deflections at the front of the intervertebral disc caused by bending (rotation) in various planes. Specimen intact. Test BB 4-5 (see Fig. 32).

Fig. 42: Lateral deflections at the right front of the intervertebral disc caused by bending (rotation) in various planes. Specimen intact. Test BB 4-5 (see Fig. 32).

Fig. 43: Lateral deflections at the right rear of the intervertebral disc caused by bending (rotation) in various planes. Specimen intact. Test BB 4-5 (see Fig. 32).

Fig. 44: Comparison of lateral deflections of the disc during forward bending before and after removal of the posterior elements. Test BB 4-5 (see Fig. 32).

Removal of the posterior joints and ligaments changed the behavior of the disc considerably in the one plane of motion tested (flexion). However, these changes in expansion and contraction were not consistent. Anterior expansion was decreased in one (Fig. 38) and increased in the other specimen (Fig. 44) during flexion. Posterior contraction of the annulus was increased on one side in each specimen and was affected little, if at all, on the other. Many more tests of this type would be required to determine the influence of the facet joints on the behavior of the disc during all types of spinal movement.

Fatigue Test

Only one fatigue test was run and it was of limited duration, both in number of cycles of stress and in time, for the disc failed after 1,000 cycles or after a test run of less than one minute (1,100 cycles per minute). Under the conditions of this test, the disc was subjected to combined axial load and bending, but only the imposed axial load was measured. Figure 45 indicates the load that the disc carried. After 200 cycles of stress, it started dropping rapidly, indicating a rapid deterioration of the disc.

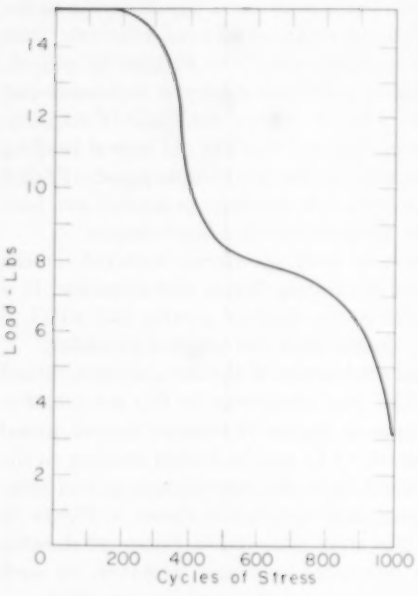


FIG. 45

Load versus cycles of stress for 0.005 inch. Deflection at a rate of application of 1,100 cycles per minute. Test FI 4-5.

Future tests will have to be run at lower values of bending moment to ensure a longer test.

Section of the specimen in the sagittal plane after the test disclosed that failure had occurred as the result of a straight horizontal tear parallel to the cartilaginous plates and approximately midway between them (Fig. 46). All the annulus fibers were ruptured except for the peripheral layers which fuse with the periosteum on the sides of each vertebra and with the anterior and posterior longitudinal ligaments. In effect, a layer of annulus less than one eighth of an inch in

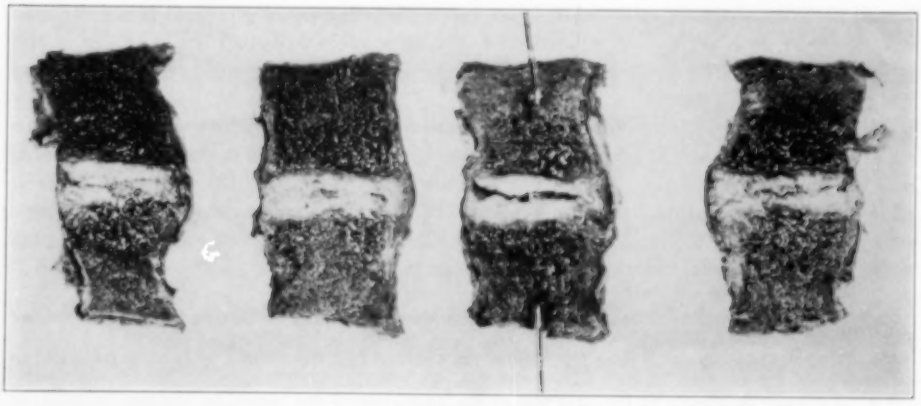


FIG. 46

Sagittal sections of specimen after failure in fatigue test. Note grossly normal appearance of annulus and nucleus pulposus except for the tear approximately midway between the plates. Grossly this tear appeared to be fresh although with respect to its locations and extent it resembled the tears seen in some extensively degenerated discs.

thickness was left surrounding the periphery of the disc. The appearance and location of this defect were not unlike those seen in extensively degenerated discs except that the tear appeared to be fresh and the nucleus pulposus was not degenerated and fragmented to the extent which would be expected with this amount of tearing of the annulus had this condition existed during life.

It is of interest that this disc of grossly normal appearance failed so rapidly with a load not exceeding fifteen pounds and with but 5 degrees of rotation occurring in the direction of flexion. No explanation for this can be offered at this time, except that the cyclic rate of stress variation was so high.

SUMMARY AND CONCLUSIONS

The investigations reported here represent an effort to explore the possibilities of obtaining quantitative data on the mechanical properties of the lumbosacral spine by applying to fresh autopsy specimens of the spine testing techniques used in civil or mechanical engineering. Few tests have been made and the data are insufficient. However, the findings to date are of interest and encourage us to continue these investigations.

With the exception of the markedly osteoporotic spines which failed at relatively low axial loads, the ultimate axial compressive load for the lumbar discs tested ranged from 1,000 to 1,300 pounds. Stiffness values for these discs ranged from 470 to 8,250 pounds per inch initially but increased to 12,000 to 20,000 pounds per inch after the applied load reached 200 to 400 pounds. Failure under axial compression took place in the vertebral end-plates even when well developed ruptures of the annulus were present. Failure of the plate ranged from imperceptible cracks to more or less complete collapse of the end-plate depending on the condition of the bone (presence or absence of osteoporosis) and on the size of the load applied.

Under the experimental conditions employed here, which involved a gradually increasing load over periods ranging from ten to thirty minutes, the volumes of five discs decreased under axial compression by from 1.0 to 2.5 cubic centimeters before failure occurred due to fracture of one of the vertebral end-plates and collapse of the underlying vertebral body. This decrease in volume is thought to be due both to collapse of the fissures and spaces ordinarily present within all adult discs and to the passage of fluid across the vertebral end-plates into the medullary spaces of the adjacent vertebral bodies.

Tests of the tensile strength of various portions of two intervertebral discs revealed that the tensile strength ranged from 0 to 700 pounds per square inch. In general, the weakest areas in both discs were the central and lateral portions. The tensile strength of three specimens of ligamentum flavum ranged from 226 to 373 pounds per square inch.

Two discs (the fourth lumbar) were subjected to combined axial loading and bending while the expansion and contraction of the discs were recorded at various points about the circumference of the annulus. During bending the discs expanded on the concave side and contracted on the convex side of the curve, while at points located at 90 degrees to the plane of motion little or no expansion or contraction occurred. The only exceptions to this general pattern of behavior were in the posterolateral portions of the discs, where annular ruptures are most frequently found. The greatest expansion and contraction occurred on the anterior aspect of these discs during straight flexion and extension.

One fatigue test was performed in which cyclic bending and compression stresses were imposed on a single disc. For technical reasons the test was not satisfactory. It is of interest, however, that rapid failure of the annulus occurred under the conditions of this experiment characterized by a horizontal tear of all but the most peripheral fibers of the annulus. The resulting picture was not unlike that seen in some extensively degenerated discs.

The findings of particular interest in the work presented here are as follows:

1. Under axial compressive stress, failure of the disc complex invariably took place

in the cartilaginous plate. In the few specimens tested the type of failure varied according to the condition of the bone rather than according to the condition of the disc. In the spines from younger individuals small cracks occurred, while in the old spines with osteoporosis, there was more or less total collapse of the plate. The similarity of the small cracks produced in these specimens to those found in the autopsy material studied by Beadle and by Coventry, Ghormley, and Kernohan was quite striking. Many [13, 27] have been inclined to assume that these defects were of little clinical significance due to their small size. However, the findings presented here suggest that such an assumption may not be valid. Failures of the end-plate may play a role in the causation of pain in some back injuries when the roentgenograms show no abnormality. In fact, Hirsch [23] reported one case in which failure of the plate was demonstrated in a man in whom sudden low-back pain developed after a strenuous effort to right an overturned car. However, the special technique of tomography was required to visualize the defect. The relief of back pain resulting from the intradiscal injection of a local anaesthetic or the anti-inflammatory hormone, hydrocortisone, might be explained by this mechanism also.

2. In these tests failure of the annulus fibrosus occurred only as the result of extremely rapid cyclic bending combined with mild axial compression. However, no protrusion of disc material was produced in this short period but rather a linear horizontal tear through all but the most peripheral fibers which still remained intact. In the one specimen in which failure was induced by flexion, the inferior posterior margin of the superior vertebra was avulsed, but the annulus remained intact.

3. It is commonly stated that the nucleus pulposus is the structure by which stresses are distributed uniformly to the annulus fibrosus and cartilaginous plates [40]. It is furthermore stated in the literature that the nucleus pulposus moves toward the convex side of the curve when the spine bends to either side or forward and backward [36]. The behavior of the two specimens subjected to combined axial loading and bending in this investigation did not seem consistent with this concept. The annulus invariably bulged on the concave side, apparently as the result of compression between the opposing vertebral surfaces. The thickest and strongest portion of the annulus, that is its anterior third, bulged the most. This would be more consistent with direct compression of the annulus than with bulging caused by deformation of the nucleus pulposus or displacement of the nucleus toward the opposite side. If there were a significant amount of displacement of the nucleus toward the convex side, it would not be anticipated that the annulus would retract on this side, as was observed in these specimens. Therefore during bending the annulus in these rather aged discs would appear to be subjected primarily to direct compression rather than to hoop tension as would be the case if its only function were to resist deformation of the nucleus pulposus. Friberg, as the result of his studies of fresh specimens of the spine, also concluded that the annulus had a weight-bearing function.

This behavior of the disc may well vary with age. The more fluid nucleus of the child may displace more during bending than the relatively fibrotic and fragmented nucleus of the adult.

4. Under axial compressive loads the volume losses of the intervertebral discs before failure in the four specimens tested were 1.0, 1.5, 2.5, and 2.5 cubic centimeters, respectively, during time intervals ranging from ten to thirty minutes. Previous clinical observations on the disappearance of water-soluble radiopaque solutions after injection into the disc space [11] have suggested that fluid transfer across the cartilaginous plates occurs quite rapidly during life even in the recumbent position when compression forces are minimal. It remains to be determined how such factors as age and degeneration of the cartilaginous plates effect the rate and amount of this transfer. Degenerative changes which occur within the disc with advancing age may be related in some way to alterations in this fluid transfer.

The experimental methods reported here are thought to show sufficient promise to

warrant a more extensive testing program on specimens from different age groups and in sufficient numbers to obtain data of statistical significance.

Furthermore, other tests would be desirable. For instance, impact tests might furnish quantitative data on the mechanism of injuries associated with falls and other sudden movements. The effect of other types of stress including shear and axial torsion would also be of interest.

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Congenital Muscular Torticollis

Etiology and Pathology

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This article is a review of the important literature on the subject of congenital torticollis. This review was made as the first part of an experimental investigation into the causes of congenital torticollis.

Congenital muscular torticollis is a distinct entity, the primary pathological characteristics of which are limited to the sternocleidomastoideus muscle [15]. The term *torticollis* is derived from the Latin words *tortus*, meaning "twisted," and *collum*, meaning "neck." Torticollis may be the result of irregular contraction of the muscles and has been described in Webster's unabridged dictionary as twisting of the neck combined with an unnatural position of the head. Synonyms sometimes used include *wry-neck*, *stiff-neck*, *caput obstipum*, *crooked-neck*, and *twisted-neck*.

There are many types of torticollis, both congenital and acquired. The most common congenital types include those resulting from muscular, osseous, or neurogenic factors, while the commoner acquired types are those resulting from infectious, neoplastic, traumatic, hysterical, or paralytic factors. Only the muscular type of torticollis, congenital in origin, will be considered here.

HISTORICAL BACKGROUND

A Dutch surgeon, Isacius Minnius, performed tenotomy for torticollis in 1685 [11]. He is believed to be the first surgeon to obtain operative correction of this condition. Previously, Girolama Fabrizio d'Aquapendente (1537–1619) had devised an apparatus for correction of torticollis.

Taylor is believed to be the first author to describe the pathological symptoms of congenital muscular torticollis. In 1875, he presented the case of a white male infant who had died at six weeks of age and upon whom an autopsy had been done. He described the deformity as an "induration of the sterno-mastoid muscle or sterno-mastoid tumour." He said that the main pathological symptom was growth of fibrous tissue between the bundles of muscle fibers. This growth had displaced and destroyed the fibers and had continued to such an extent that, in some areas, the muscle was double its usual thickness. The changes were present throughout the muscle. He illustrated this case report by a drawing of a microscopic section of the affected muscle showing the fibrous tissue between the muscle fibers.

In 1893, Anderson stated that not until the eighteenth century was torticollis described in surgical textbooks. He said that Samuel Sharp, writing in 1740, did not feel that congenital wry-neck should be treated by surgery and that the first man to give serious consideration to surgical treatment of this condition was the great French surgeon Dupuytren.

EVOLUTIONARY DEVELOPMENT OF THE STERNOCLEIDOMASTOIDEUS

Straus and Howell, in a monumental paper written in 1936, carefully trace the evolutionary development of the sternocleidomastoideus muscle, basing their discussion on the well known fact that the innervation of a muscle is a good indication of its primitive origin. The following information is based entirely upon the work of these two authors.

Anatomists have long been puzzled by the fact that in mammals the musculature comprising the trapezius and sternocleidomastoideus is innervated both by the spinal part

of the accessory nerve and by branches of the anterior rami of the cervical nerves. Since the source of innervation of a muscle is an accurate indication of its origin and since it is almost universally believed that the spinal part of the accessory nerve is of visceral derivation, it has been conjectured that the trapezius-sternocleidomastoideus complex is itself of visceral origin. The double innervation of this musculature in mammals is unique. On the basis of this anatomical feature, it is felt that these muscles either (1) are of compound visceral somatic origin or (2) are primarily visceral in origin but contain components which later shifted to follow a somatic (spinal) pathway. According to Edgeworth, the primordial origin of the trapezius-sternocleidomastoideus musculature in a variety of vertebrates is the region of the branchial arches.

In the dogfish (Squalus), a typical genus of the Elasmobranchii, the nerve to the trapezius musculature is simply the largest and most posterior of the branchial rami of the vagus nerve which supplies segments of the gill musculature. The trapezius musculature (the sternocleidomastoideus is undifferentiated in this genus) consists of a single tissue arising from the skin and superficial fascia over the muscles of the back. It inserts not only in the shoulder musculature and in the girdle but also in the cartilage of the upper portion of the last branchial arch. It is thus perfectly in sequence with the small lateral interarcuate muscles of the other gill arches. This seems to indicate that the trapezius musculature is a specialized, posterior division of the interarcualia which are branchiogenic. Thus, it appears that the trapezius musculature, which includes the sternocleidomastoideus, is probably of visceral origin. In sharks, this musculature is larger and more powerful and serves to move the girdle. In bony fish the membranous girdle cannot be moved because of its firm attachments, as a result of which the attached visceral muscles can move only part of the gill apparatus. Because of this anatomical difference the visceral muscles are much weaker in bony fish than they are in the dogfish. In some fish, especially the Teleostei, this muscle mass is not even present as a result of extreme specialization during evolutionary change. In all fish, the trapezius-sternocleidomastoideus musculature is innervated, so far as is known, solely by the posterior twig of the vagus branches which supply the posterior part of the gill musculature.

The trapezius mass is also undivided in amphibians, the sternocleidomastoideus not being differentiated from the main mass. In most Caudata, the trapezius mass is a broad tissue arising from the superficial fascia of the back. The musculature of the common toad is an exception in that it is very narrow and tends to arise exclusively from the head so that it more closely resembles a sternocleidomastoideus than a trapezius. According to most authorities, the sole source of innervation of this muscle in amphibians is a branch of the vagus; Norris (1913) has reported, however, that in *Siren lacertina* the small dorsal branches of the first and second spinal nerves are also sources. It is extremely likely that the spinal branches involved carry only sensory fibers. In summary, so far as is known, amphibians have an undivided muscle mass which represents the accessory field of musculature and which is innervated by a branch of the vagus nerve. In some species this musculature may also be partly innervated by spinal nerves.

The accessory field of musculature in reptiles arises from the aponeurosis on the dorsal side of the shoulder girdle and from the posterior portion of the cranium. Its insertion is located on the anterior border of the scapula above the clavicle, along the entire length of the clavicle, and on the interclavicle. In species of reptiles now extinct, the insertion was probably located along the length of both the cleithrum (a structure which is not found in extant species) and the clavicle, and in these reptiles the function of the trapezius mass was to advance and, at the same time, elevate the girdle. Furbinger, in 1900, demonstrated that in extant species of Lacertilia there may be found all stages of development, from the stage in which the muscle is an undivided mass to the stage in which the sternocleidomastoideus element is completely distinct. These are the lowest animals in the evolutionary scale in which the trapezius-sternocleidomastoideus muscula-

ture is divided. Since division of this muscle mass is not present in vertebrates below the reptiles in the evolutionary scale, it seems conclusive that the accessory field of musculature has developed from a single source, the dorsal branchiomeric unit, rather than from two (dorsal and ventral) sources, as the condition in mammals indicates. The reptile is also the lowest animal in the scale in which the accessory field is regularly innervated by the spinal nerves as well as by the visceral nerves. Apparently, in most classes the spinal nerves are afferent in nature. On the basis of their experimental work, Straus and Howell concluded that these afferent fibers, which in the lower vertebrates presumably follow the pathway of the vagus, have, in reptiles, shifted so that they follow a spinal route. Furthermore, some motor fibers also follow this new pathway.

The accessory field of musculature is present in all mammals. Furthermore, in all mammals there is a distinct portion which represents the sternocleidomastoideus, although in some species this portion may be partially covered by the trapezius. There may be separate slips of origin from the sternum and clavicle and separate insertions upon the mastoid process and occipital bone. These various sections of the muscle may be individually named—for example, the sternomastoid portion, the sterno-occipital portion, the cleidomastoid portion, and the cleido-occipital portion. In all but a few of the higher forms of animal life, innervation is obtained by both the spinal accessory nerve and the cervical nerves. In mammals a larger proportion of the motor fibers follows the spinal-nerve course, and the source of innervation of the trapezius and sternocleidomastoideus muscles is more frequently double. The shifting of the motor fibers to follow the spinal-nerve course is similar to but more extensive than that found in reptiles.

In summary, the evidence seems to indicate that the origin of the trapezius-sternocleidomastoideus musculature is visceral. This muscle mass apparently originally developed in the branchial-arch region and when it shifted, its visceral-nerve supply shifted with it. In the lower forms, this mass is supplied by the vagus nerve, but in the higher forms it is supplied, in the main, by the spinal accessory nerve, the nucleus of which is closely related to the nucleus of the vagus nerve and is thought by some to have originally been part of the vagus nucleus. Thus, it appears that in higher forms the nerve supply of the sternocleidomastoideus muscle and the trapezius muscle may be related to the nerve supply of the muscles of the gastro-intestinal tract.

EMBRYOLOGY OF THE TRAPEZIUS AND STERNOCLEIDOMASTOIDEUS IN THE HUMAN

Lewis, writing in the *Manual of Human Embryology*, gives the following information on the embryology of the trapezius and sternocleidomastoideus.

The trapezius and sternocleidomastoideus are derived from the mesoderm. They arise in the lateral portion of the occipital region as a common muscle mass and later migrate to the shoulder girdle. At a very early period, the accessory nerve extends into this muscle mass, and as the mass extends caudally, the nerve is carried with it.

The common rudiment of the trapezius and sternocleidomastoideus first appears when the embryo is about seven millimeters long. It lies anterior to the two caudal occipital and two anterior cervical myotomes. Its position is determined more by location of the branchial-arch series than by the location of the myotomes, however. No direct observations concerning the origin of the cells composing this rudiment have been made, but from its position and nerve supply it seems that it is the caudal member of the branchial-arch series. In this early stage, it consists of closely packed cells and is indistinguishable from the surrounding mass of mesenchymal cells except for its greater condensation and except for the presence of the accessory nerve which runs for some distance within it. The anterior end of the muscle mass lies close to the region in which the accessory nerve leaves the vagus. From this point it gradually extends caudalward toward the arm bud of the pre-muscle tissue, which in a nine-millimeter embryo is located at about the level of the fourth cervical myotome. At this stage its caudal end already shows some

signs of splitting into the two divisions from which the sternocleidomastoideus and trapezius develop.

In an eleven-millimeter embryo, the two caudal divisions are quite widely separated. The trapezius portion extends to about the sixth cervical nerve, while the sternocleidomastoideus portion extends nearly to the rudimentary clavicle, which at this stage lies far anterior to the first rib. The trapezius is not yet attached to the shoulder girdle but is a thick columnar mass extending from the occipital region caudalward, parallel and close to the vagus nerve. It extends only slightly toward the spinous processes and is connected with them by a layer of fascia. The thick deep cervical fascia separates it from the more dorsal myotomic muscle masses.

In a sixteen-millimeter embryo, the entire arm and shoulder girdle have migrated caudally. The trapezius and sternocleidomastoideus are now separate throughout their entire length. The trapezius is attached to the spine of the scapula and adjoining portion of the clavicle. It has extended caudally as far as the sixth rib and dorsally toward the spinous processes and the ligamentum nuchae. The anterior end of the muscle does not extend as yet to the occipital cartilage. Not until after the embryo is over twenty millimeters in length does the trapezius obtain its final form. The splitting of the trapezius into divisions may sometimes be found in the adult as a secondary process; it is not present in the early embryo.

The sternocleidomastoideus also shows marked development in a fourteen-millimeter embryo and extends from the mastoid process and occipital region to the clavicle. It has already begun to split into two divisions corresponding to the sternomastoid and cleidomastoid. The accessory motor nerve supply from the cervical region to the trapezius and sternocleidomastoideus is secondary and does not indicate a myotomic origin for any portion of the muscle.

EMBRYOLOGY OF THE NERVE SUPPLY TO THE STERNOCLEIDOMASTOIDEUS AND TRAPEZIUS IN THE HUMAN

Streeter, also writing in the *Manual of Human Embryology*, presents the following facts.

The vagus complex is composed of several branchial nerves, including the vagus and accessory nerves. In man, the motor fibers of this complex are specially adapted to supply the group of muscles derived from the branchial arches. In the higher forms the more caudal rootlets of the vagus are predominantly motor and form a distinct bundle which is known as the spinal accessory nerve. This bundle is distributed to the group of muscle cells which are derived from the more caudal branchial arches, and in man it functions to innervate the muscles of the arm girdle—the sternocleidomastoideus and trapezius. As these muscles grow, the nerve is carried down across the neck. Coincidental with the increased importance of this musculature in the higher vertebrate forms, there is increased development of the accessory nerve; additional rootlets of origin are obtained by extension down into the roots of the spinal cord. These rootlets may extend as far down as the fourth cervical segment. The nucleus of origin of the spinal accessory and other border rootlets of the vagus is composed of the nucleus ambiguus of the medulla oblongata and a portion of the lateral region of the spinal cord, the two being continuous.

ANATOMY OF THE STERNOCLEIDOMASTOIDEUS AND TRAPEZIUS IN THE HUMAN

In 1948, Grant stated that the trapezius and sternocleidomastoideus have a continuous attachment which extends from the inion to the tip of the mastoid process. This attachment is aponeurotic and therefore produces a ridge, the superior nuchal line. The position of the mastoid process which constitutes one end of this line is the result of the downward, forward, and medial pressure exerted by the pull of the sternocleidomastoideus. Below, one head of the sternocleidomastoideus is attached to the superior border of the

medial third of the clavicle, while the other head crosses in front of the sternoclavicular articulation and is joined by fibrous tissue to the sternum just below.

Chandler and Altenberg have written that "the sternocleidomastoid muscle is a large lateral oblique muscle which extends from the anterior superior portion of the pectoral girdle to the mastoid region of the temporal bone of the skull. It is enveloped by a double layer of the external cervical fascia. It has two heads of origin and one composite head of insertion. It is usually made up of five or more distinct muscle bellies. Those found most consistently in dissections were (1) superficial sternomastoid, (2) superficial sterno-occipital, (3) superficial cleido-occipital, (4) deep sternomastoid, and (5) a double deep cleidomastoid."

In Morris' *Human Anatomy* it is stated that the medial or sternal portion of the sternocleidomastoideus arises from the front of the manubrium just below the clavicular notch and that the lateral or clavicular head arises from the upper border of the medial third of the clavicle. Between these origins there is a triangular area covered by external cervical fascia. The muscle inserts (1) into the anterior border and outer surface of the mastoid process and (2) into the lateral half of the superior nuchal line of the occipital bone. The tendons are comparatively short and the fiber bundles follow a nearly parallel course from origin to insertion.

BLOOD SUPPLY

Middleton, in 1930, wrote that the sternocleidomastoideus muscle is divided into three major portions. The upper portion is much shorter than is generally believed. It is located at the mastoid end of the muscle and is supplied by the superior portion of the sternocleidomastoid artery which is derived from the occipital artery. This artery is short and follows a transverse course. The venous return from this portion of the muscle appears to travel through short trunks which penetrate the deep aspect of the muscle and join the large veins beneath.

The sternal head of the muscle receives its arterial supply through the middle portion of the sternocleidomastoid artery, a branch of the superior thyroid artery. This branch separates from its parent trunk a short distance above the upper border of the omohyoideus muscle and runs backward and downward parallel to the upper border of the omohyoideus muscle. On reaching the sternal head of the muscle, it does not enter the head at once but instead passes beneath it, reappearing in the interval between it and the clavicular head. The artery then courses downward along the posterior border of the sternal head to which branches are extended (there are no branches to the clavicular head). The vein from the sternal head appears to follow the artery of supply and eventually terminates in the pterygoid plexus formed by the junction of the superior thyroid and lingual veins with the common facial vein.

The clavicular head derives its arterial supply from the inferior portion of the sternocleidomastoid artery by means of a small branch which comes either directly from the thyrocervical trunk or from one of the branches of this trunk, the transverse scapular artery. The branch runs upward through the deep aspect of the muscle to which branches are extended. The exact path of the venous return from this head is uncertain.

Fitz Simmons [20] has written that the sternal and middle portions of the muscle receive their blood supply from the sternocleidomastoid branch of the superior thyroid artery.

According to Chandler and Altenberg, the arterial supply is extensive and comes from five or more main sources: (1) the occipital branch of the posterior auricular supplies the upper portion of the muscle near its aponeurotic insertion; this branch frequently anastomoses with the occipital artery; (2) either the sternocleidomastoid artery or muscular branches of the occipital artery supply the portion of the muscle to which are attached the many large major branches which ascend and descend in each muscle belly;

(3) the sternocleidomastoid branch of the superior thyroid artery supplies the middle portion and part of the lower third of the sternocleidomastoideus muscle and sends two main branches, as well as many small branches, down the chief muscle division; (4) a branch of the transverse scapular artery supplies the lower portion of the muscle by means of many secondary branches; and (5) an arterial branch which arises from the ascending branch of the transverse cervical artery supplies the lower lateral portion of the muscle.

The vessels which provide the venous drainage of the sternocleidomastoideus muscle are even more profuse than are the arterial vessels. Not only is there overlapping of the areas of venous drainage but also there are numerous communications between the main venous channels, both within the muscle substance and on the surface. The venous return of the sternocleidomastoideus is carried by all the major veins of the neck—the internal jugular, the external jugular, the anterior jugular, the transverse scapular, the occipital, the posterior auricular, the posterior facial, and the anterior facial veins. There are frequent and profuse communications not only between the main venous channels but also between their branches both on the surface and within the muscle tissue itself.

NERVE SUPPLY

In 1915, Fitz Simmons wrote that the sternocleidomastoideus receives its nerve supply from the spinal accessory. The external portion of this nerve leaves the skull by the jugular foramen and descends obliquely outward to the sternocleidomastoideus muscle, disappearing under the muscle at a distance of about two inches from the apex of the mastoid process.

The branches supplying the sternocleidomastoideus are both visceral and somatic. The motor branches arise chiefly from the visceral fibers of the spinal accessory nerve. The sternocleidomastoideus also receives motor and sensory fibers from the second, third, and fourth cervical nerves. The spinal accessory follows a deep course in this region, and it usually lies between the bellies of the cleido-occipital portion of the muscle and the middle third, following closely the course of the muscular branches from the occipital artery.

Arey has written that the spinal accessory nerve is really a part of the vagus complex. This complex innervates the sternocleidomastoideus and trapezius muscles, which are usually regarded as of branchial-arch origin.

FUNCTION

According to Morris' *Human Anatomy*, the function of the sternocleidomastoideus is to bend the head and neck toward the shoulder and to rotate them toward the opposite side. When the trapezius also acts, the neck is flexed and the chin is raised. When the head is fixed, the two muscles may further increase the degree of hyperextension. Actually, in the simplest terms, the sternocleidomastoideus rotates the occipital bone to the same side and the chin to the opposite side.

ETIOLOGY

In a discussion of the etiology of congenital muscular torticollis, the ultimate, or remote, cause of this condition must be considered as well as the immediate cause. With regard to the immediate cause, it probably matters little whether it is considered to be (1) fibrosis within the sternocleidomastoideus muscle, with subsequent contraction similar to fibrotic scar contractions elsewhere in the body, or (2) static fibrosis of the sternocleidomastoideus with relative shortening due to a rapid increase in the length of the neck during the stages of accelerated growth, or (3) a combination of both mechanisms. It is the remote cause which has stimulated the most interest through the years and about which the least is known. If it is postulated that the presence of a fibrous tumor resulting in fibrous-tissue replacement of the muscle is the immediate cause of torticollis, it is tempting to inquire as to the origin of the fibrous tumor.

Determination of the predisposing factors is apt to be even more difficult. It might be argued that because some babies with torticollis are born in the breech position, it follows that breech presentation can be considered a predisposing factor in congenital wry-neck. On closer attention to the problem, however, we find that it would be possible for wry-neck to be a causal factor in the breech presentation. Recent studies of clinical records tend to confirm the latter interpretation.

A number of theories as to the cause of congenital muscular torticollis have evolved in the past two and one-half centuries. It is a matter of interest that in 1670 van Roonhysen, in one of the first recorded works on torticollis, attributed this condition to abnormal pressure on or position of the head *in utero*. Thus, at the outset, the antenatal existence of torticollis was postulated. In 1838, Stromeyer formulated the theory of birth injury, and it was to be nearly a century before the antenatal theory was revived. Stromeyer believed that the sternocleidomastoideus is ruptured during labor, giving rise to the "sternomastoid tumor," which he felt is in reality a hematoma; the contracture which develops following the organization of this hematoma is responsible for the wry-neck deformity. From a pathogenetic standpoint, Stromeyer thought that the development of the hematoma is followed by myositis which may involve and ultimately destroy a large part of the substance of the muscle, replacing it with fibrous tissue; contraction of this muscle causes the wry-neck deformity.

In 1883, Witzel wrote that hematomata produced experimentally by the tearing of muscles leave no contracture and in no way resemble the tumors of the sternocleidomastoideus seen in congenital muscular torticollis, findings which contributed to disproving the hematoma theory.

Petersen, in 1884, 1886, and 1892, reported his attempts to combat Stromeyer's hematoma theory which was widely accepted. Petersen stated that the formation of true hematomata is not followed by the development of torticollis. He believed that adhesions form between the amnion and the face of the embryo and that these bring about a position of the head which interferes with the development of one of the sternocleidomastoideus muscles, for when one side of the face adheres to the amnion, the body of the embryo falls in the opposite direction. In this situation, he postulated, the development of the sternocleidomastoideus muscle on the side of the adhesion is not interfered with but the points of insertion of the muscle on the opposite side are brought closer together, causing a lack of development on that side.

Volkmann, in 1885, initiated the infectious theory of congenital muscular torticollis. This author believed that the changes in the muscle are the result of an inflammatory process, for microscopic studies of sections of a sternocleidomastoideus from a patient with wry-neck revealed the presence of some of the characteristics of infectious myositis. He believed that this finding indicated the occurrence of an infection in intra-uterine life and that torticollis results from the fibrosis which develops subsequent to the myositis.

A few years later, in 1890, Schmidt returned to the old intra-uterine, antenatal theory, but added some variations. He regarded the pressure of the mother's liver upon the uterus as sufficient to explain the development of wry-neck in an infant presented by breech. Conditions he regarded as favoring the development of wry-neck included breech presentation, pelvic deformity, primiparity, and the presence of a small amount of amniotic fluid. That same year, in 1890, Golding-Bird originated the neurogenic theory. He felt that the cause of the deformity is the occurrence of a cerebral lesion during intra-uterine life, following which development of the sternocleidomastoideus is arrested.

Anderson, writing in 1893, believed that there are really two types of torticollis, the truly congenital type, which arises during intra-uterine life, and the type for which the foundation is laid by an accident during parturition. He considered that there are three possible causes of the former type: (1) arrest of the development of the face and neck; (2) disease of the nerve centers affecting the side of the neck secondarily; and (3) mal-

position of the head of the foetus *in utero*. The second type of torticollis he felt might be due to injury of the muscle *per se* during parturition. Although Anderson added little to the conception of the causes of torticollis, he did bring out that the so-called tumor of the sternocleidomastoideus, which formerly had been thought by some to be due to lues, is probably not syphilitic in origin.

Mikulicz, writing in 1895, suggested ischaemia as a cause of torticollis. This theory actually involved two factors, general ischaemia (actually anoxia) and trauma to the sternocleidomastoideus muscle. He reasoned that compression of the umbilical cord induces forced respiratory movements while the fetal head is still engaged in the maternal passage; the sternocleidomastoideus muscle, being one of the muscles involved in the forced inspiration, is contracted and thus is more vulnerable to rupture—a rigid muscle rupturing more easily than a relaxed muscle. Mikulicz also accepted the theory that infection is a cause of torticollis. Kader, writing in 1897, thought that infection of the muscle, especially if the infection is of hematogenic origin and if it occurs in a muscle which has been injured, is a factor; he thus combined the traumatic and infectious theories.

Most of the theories on the cause of torticollis accepted today were first expressed prior to 1896: (1) intra-uterine theory, (2) birth-trauma theory, (3) infectious theory, (4) neurogenic theory, (5) ischaemia theory, and (6) combinations of the above theories. During this time, however, little experimental work had been done concerning the pathology of the condition.

In 1898, Heller, using dogs as experimental animals, demonstrated that it is impossible to cause myositis and contracture of a muscle by means of trauma unless the muscle is infected by pyogenic organisms. In addition, he showed that in dogs muscles ultimately shorten when their points of attachment are permanently brought nearer together. This might be considered as evidence in favor of the old theory of intra-uterine malposition. Because of his belief in the relation of the hematoma to the myositis found in congenital muscular torticollis and as a consequence of his experiments which showed that muscle contraction occurred only in the presence of actual infection, Heller assumed that an infection of the traumatized area of muscle by means of organisms reaching the muscle through the blood stream was a possible cause of wry-neck. Thus, he reached the same conclusions as Kader had reported a year earlier.

In 1899, Bradford and Lovett summarized the main etiological theories then known but added no new facts or interpretations. They described experiments upon rabbits in which hematomata of the sternocleidomastoideus were produced and stated that the results were negative ("negative" is interpreted to mean either that wry-neck deformities did not develop or that the pathological characteristics of the lesions did not resemble those seen in congenital muscular torticollis). They had made follow-up studies of infants in whom the sternocleidomastoideus had been ruptured at birth and had found that torticollis did not develop as a result of this trauma. Three years later, in 1902, Völcker reported that the so-called hematomata were probably postobstructive oedema. He described, for the first time, the presence of torticollis in infants following extra-uterine pregnancy. The reason for the ischaemia, according to Völcker, was prolonged partial obstruction of the blood supply to the muscle; the mechanics of the obstruction were not clear, however. In 1903, Gallavardin and Savy reactivated the neurogenic theory by writing that they had observed atrophy of the anterior horn cells in the cervical cord in an adult with torticollis. The following year (1904), Kempf showed that there was no microscopic evidence for the belief that infectious myositis was responsible; he stated that the microscopic appearance of the excised muscle is that of a healed hemorrhagic infarct.

Joachimsthal, writing in 1905, also described a case in which torticollis occurred following an extra-uterine pregnancy. It is believed that he is the first to describe the presence of other congenital deformities in association with torticollis. A child of four and one-half years had a typical case of wry-neck on the right side as well as bilateral club-foot,

deformed toes and fingers, and a deformity of the head. Joachimsthal was also the first to report hereditary transmission of torticollis.

In 1906, a new theory concerning the etiology of congenital muscular torticollis was developed—the theory of arterial occlusion, as conceived by Nové-Josserand and Viannay. These men based their theory chiefly on the work which they had done with stillborn infants. They reported that their anatomical studies had demonstrated three systems of blood supply to the sternocleidomastoideus. They stated that each system is an independent unit which supplies its own portion of the muscle and which does not communicate with either of the other systems or with the surrounding arteries. From the configuration of the arterial supply to the muscle, they reasoned that the venous systems are also independent. They then proceeded to show that in the foetus the arteries of the sternal and clavicular heads can be occluded if the head is in a position of extreme rotation such as occurs during labor, for when the head is in this position, the tensed sternocleidomastoideus may compress the vessels of supply where they pass beneath it. Nové-Josserand and Viannay believed their work showed that interference with the blood supply of the sternocleidomastoideus may occur during labor.

Schloessmann, in 1911, stated that the cause of torticollis was arterial occlusion. The first recorded case of bilateral torticollis was described by Morse in 1915. He presented the case of an infant delivered by caesarian section and stated that the condition was not caused by a birth injury. He thought that the cause for the bilaterally shortened muscles was the partially extended position the fetal head may have occupied *in utero*.

Bevan, in 1918, wrote that congenital wry-neck is caused by an injury of the sternocleidomastoideus muscle during birth, followed by hemorrhage in and around the muscle and its sheath. As a result of this trauma, histological changes occur in the structure of the muscle. The contracture is not limited to the muscle itself, for the deep cervical fascia which forms the sheath of the muscle is also extensively involved. In addition there is a marked change in the platysma muscle. This is not due to fibrous degeneration but rather is caused by the head being held on one side, which causes marked reduction in the size of the platysma, although as a rule it causes no alteration in its histological structure. In 1920, Sippel re-emphasized the intra-uterine theory.

Meyerding, in 1921, thought that trauma to the sternocleidomastoideus at or preceding birth causes ischaemia which results in chronic interstitial myositis. "The ischemia may," he wrote, "result from pressure upon the sternomastoid branch of the superior thyroid artery or from a hematoma into or around the sheath of the muscles affected." Schubert, in the same year, wrote that heredity may play an important part in torticollis.

In 1923, Jones and Lovett supported the theory that torticollis is caused by abnormal intra-uterine position or by increased intra-uterine pressure. They used as evidence the fact that congenital club-foot, due to the same cause, is often an associated deformity. They added that hematomata must also be recognized as a possible cause, for although in some cases they are not followed by the development of wry-neck, in other cases wry-neck does occur. They emphasized that a previously shortened muscle may easily be ruptured. Krogius, in 1924, is thought to be the first to suggest the theory that congenital muscular torticollis has an endogenous origin, being the result of an anomaly in the muscle blastoma itself. He believed that the development of this condition is an anatomical-pathological process which consists in connective-tissue or tendon formation at the expense of muscle-tissue formation, the tissue originating from the perimysium. He felt this process continues for years and that it is not a sequel to ischaemic muscle degeneration. He was thus the first to believe that the development of torticollis is an active process lasting many years following birth.

Stern, in that same year, gave his reasons for supporting the intra-uterine theory. He reported an unusual case to support the theory that congenital muscular torticollis is due to an abnormal position of the foetus and to a lack of space in the uterus. In this

case the infant was in the breech position and was delivered by caesarian section. In 1925, Bauman stated that in no case had injury to the sternocleidomastoideus been followed by the development of torticollis. Fitz Simmons [21] stated that in the majority of infants with congenital torticollis the condition is not due to obstetrical trauma. This observation was based upon a study of more than 500 cases. Some of the infants with torticollis in this series had been carried outside the uterus during pregnancy and some had received no trauma; in some the development of hematomata following strenuous delivery or injury was not followed by the development of torticollis.

Rugh, writing in 1925, felt strongly that in the majority of cases the origin of the condition is traumatic rather than congenital. Sever, in the same year, stated flatly that he had never seen a case in which torticollis had developed following the development of a hematoma. Aberle, in 1927, emphasized the heredity factor. He quoted Petersen, Friedberg, Spitzy, and others who had reported that, in a number of cases, the development of hematomata had not been followed by the development of torticollis. Colonna, in the same year, stated his belief that abnormal position *in utero* is a cause. Also during that year, Hellstadius stressed the heredity theory. Rossi, in 1928, made a complete study of the case of a child delivered by caesarian section. He referred to the theory advanced by Petersen, who maintained that there is a connection between the pathogenesis of the condition and the intra-uterine life of the foetus, describing the mechanism as an abnormal pressure exerted by the uterine walls. The pressure forces the foetus into a faulty position with rotation and flexion of the neck. This position, in turn, causes an abnormal shortening of the distance between the points of insertion of the sternocleidomastoideus, resulting in torticollis. Petersen, on the basis of numerous experiments on animals and on the basis of his clinical observations, had concluded that the faulty intra-uterine position of the foetus is related to amniotic adhesions, to oligohydramnios, and to various other conditions which also produce anomalies.

Middleton, in 1930, stated that he was unable to demonstrate the presence of thrombosed veins in the sternocleidomastoideus. He pointed out that the sternocleidomastoideus tumor does not have the characteristics of a hematoma, for there is never any ecchymosis or fluctuation and from the onset the mass is firm, hard, and feels cartilaginous. Furthermore, the process is diffuse instead of localized and there is an interval of one to two weeks before the tumor appears, which is not consistent with hemorrhage. Excision of a tumor definitely proved it was not due to hemorrhage. Bargellini, in 1931, presented his reasons for supporting the heredity theory. Fitz Simmons, in 1933, wrote that since, under experimental condition, the middle and inferior sternocleidomastoid arteries can be closed to injection when the neck is in a certain position, it would seem that the thin-walled veins may be shut off during labor without the arterial supply being interrupted, with the result that, temporarily at least, there is produced the same condition as is obtained experimentally by venous ligation. Abels, in 1934, expressed his belief that changes in the muscle occur as a result of intra-uterine malposition and are aggravated by birth trauma. De Gaetano, in the following year, held essentially the same view, and Jahss in 1936, described a type of torticollis which is due to a shortened clavicular head. In 1937, Schmid repeated the theories that stress the heredity factor. Abels, in an article written in 1938, stated that the position of the foetus is a direct cause.

Kastendieck, in 1939, supported the intra-uterine theory. Shands and Raney, writing in 1940, stated that some observers believe that the origin of torticollis is rupture of the muscle fibers during birth. The rupture is accompanied by formation of a hematoma and subsequent replacement of a part of the muscle by scar tissue; incomplete regression of the hematoma may be followed by the development of contracture of the sternocleidomastoideus. Janěk, the next year, affirmed his belief in the traumatic factor—birth injury. Christian, in *Osler's Principles and Practice of Medicine*, stated that in congenital wryneck the sternocleidomastoideus is shortened, hard, and firm and is atrophied to a con-

siderable degree. This condition must be distinguished from local thickening of the sternocleidomastoideus due to rupture, a condition which may occur at birth and which may produce an induration. Chandler and Altenberg, in 1944, stated that muscular torticollis results, not from a single type of pathological disturbance, but from a number of contributory factors which may act separately or together. In their opinion intra-uterine malposition and the local ischaemia and pressure which may be caused by this malposition contribute to the development of muscular torticollis by rendering the muscle atrophic, maldeveloped, fibrous, shortened, and ischaemic. They felt that trauma during delivery may also be a factor.

Johnson, the next year, wrote that the muscle may become contracted *in utero* or may undergo fibrosis and shortening as a result of stretching and tearing during delivery. He added that in many cases a hematoma can be palpated in the muscle during the first week after birth. Chandler, in 1948, stated that it is recognized that contracture of the sternocleidomastoideus may exist prior to birth. Stevens, in the same year, described congenital muscular torticollis in identical twins. The condition was on the right side in both infants and there was greater involvement of the clavicular head than of the sternal head. He considered the condition to be a congenital anomaly.

In 1950, Hulbert reviewed 100 cases. He classified the patients into two groups, those with postural torticollis in which there was no associated tumor formation and those with muscular torticollis in which there was associated tumor formation. He felt that the findings of histological studies did not support the ischaemic theory and that some other prenatal factor was probably the cause of the condition. Also in 1950, Greenstein observed a case of congenital muscular torticollis in an infant delivered by caesarian section. The operation was performed before the onset of labor, two weeks prior to the expected date of delivery.

PATHOLOGY

The earliest known description of the pathology, as seen microscopically, was written in the latter part of the nineteenth century. Taylor, in 1875, presented a case of a six-week-old white male upon whom autopsy had been done. In this report he described the condition as induration of the sternocleidomastoideus muscle or sternocleidomastoideus tumor. He stated that, to his knowledge, his case was the first on record in which the histological character of the lesion had been ascertained. It was found that fibrous tissue had developed between the bundles of muscle fibers, displacing and destroying these fibers and extending to such a degree that in some parts the muscle was double its usual thickness. Study of a section of the tumor showed dense, white fibrous connective tissue or, in many places, white fibrous tissue. In the middle portion of the muscle, where it was most dense and nodular, fibrous tissue alone was present and no striated muscular fibers could be seen. At the upper end of the muscle, the muscular tissue was only moderately abundant on the surface. Some of the fibers of this tissue were normal in appearance and size, while others were narrow, twisted, and of varying breadth and were less distinctly striated than normal. All were surrounded by a considerable quantity of fibers and elastic tissues, but there were no features of early cell growth. Deeper in the substance of the upper end of the muscle there was an excessive amount of fibrous tissue in which tolerably well preserved muscle fibers lay isolated in the midst of the waxy bands. The new growth of fibrous tissue was neither completely localized nor uniformly diffuse.

One of the most interesting secondary changes in congenital muscular torticollis—asymmetry of the skull and face—was carefully described by Witzel in 1883. He reported that the affected side of the head and face becomes atrophic and that measurements reveal that the distance from the external canthus to the angle of the mouth is less than it is on the normal side. He also reported that the eyebrow is less arched, the nose is deflected, and the cheek is less full. No satisfactory explanation of this condition has been offered,

but Witzel thought it is probably due to imperfect blood supply. The asymmetry diminishes if the torticollis is treated early.

In 1891, in a discussion of a paper by Whitman, Hadra claimed priority for developing the open operation which he stated he had first described in a paper published in the New York Medical Record in 1884. He said that in two cases microscopic examination had shown that the muscle had entirely disappeared and that its place had been taken by cicatricial tissue. He found it hard to believe that such extensive degeneration could have occurred unless the condition was of intra-uterine origin.

In 1891, Whitman reported seven cases in which swelling of the sternocleidomastoideus muscle was present but in which no torticollis subsequently developed. He claimed that torticollis is not caused by a hematoma of the sternocleidomastoideus muscle.

In 1892, H. R. Spencer reported that hemorrhage in the sternocleidomastoideus had been observed at autopsy in fifteen of nearly 300 children who either had been stillborn or had died shortly after birth. Ten of the infants had been in the breech or footling position; in two cases forceps had been used in delivery and in two no instruments had been used. According to Spencer, the microscopic sections in nine cases revealed hemorrhage into the anterior portion of the upper two-thirds of the muscle. As a result of the hemorrhage the muscle was dark red, had a firm consistency and was one-third of an inch thick at the edge. The low-power view showed connective tissue, infiltrated with blood, separating the vessels and muscular fibers. The high-power view showed blood effusion in large amounts between fasciculi and also, in places, between individual fibers. Some fibers appeared more granular than others and many were ruptured. Some had large bulbous ends. The sarcolemma in some cases was still intact, although the muscle substance had given way. The fibers showed longitudinal and transverse striations, the latter often being indistinct, wavy, and coarse. In many fibers there were swollen areas and in these areas the fine transverse striations were usually more uniform. Spencer concluded that the distribution of the extravasated blood in these infants was similar to that seen by other authors in the fibrous tissue of older children.

In a discussion of torticollis at a meeting of the British Royal Medical and Chirurgical Society in 1893, Parker said that in an infant five weeks old he had cut into the swelling of the sternocleidomastoideus and had found nothing resembling blood. In this same discussion W. G. Spencer stated that in an operation performed by Volkmann it had been found that the anterior and posterior layers of the muscle sheath had been converted into cartilaginous masses one-half inch thick. Microscopic study of these masses had revealed that they contained some muscle fibers and ordinary scar tissue. In concluding the discussion Power said that he had found no trace of pigment or altered blood clot within the muscles of new-born infants with torticollis.

Mikulicz, in 1895, studied specimens of muscles that had been partially or totally excised from twenty-one infants with wry-neck and said that changes were present even in parts of muscle which microscopically appeared normal and that connective tissue had formed in place of the muscle fibers. Hildebrand, in 1897, reported that study of microscopic sections had indicated that marked decrease in the muscle fibers in the region of the tumor had occurred in an eight-week-old child. Many fibers still remained functional, however, and no blood pigment had been demonstrated. The diagnosis was interstitial myositis.

In 1903, Völcker described a peculiar degeneration of muscle fibers which had developed after prolonged partial obstruction of the circulation of the muscle. These changes had been observed microscopically in sternocleidomastoideus muscles excised from patients with congenital torticollis. Völcker believed that the hematomata reported were probably postpartum oedema. In 1905, Heusinger reported the case of a fourteen-day-old infant with a sternocleidomastoideus muscle which was nine centimeters long. Pathological study showed a swelling the size of a hazelnut which had developed two days after birth. Micro-

scopic study revealed chronic interstitial myositis with no trace of blood pigment. Heusinger felt that this condition must have originated during intra-uterine life and that a true hematoma could not have existed.

In 1911, Jacobs wrote that as a result of the abnormal position of the head, lateral curvature of the cervical spine is always present, the convexity of the curve being directed away from the affected side. Occasionally, there is also a secondary compensatory curve in the lower thoracic region. In 1915, Morse summarized the pathological findings reported by several authors: Völcker had demonstrated degenerative changes in the muscle, Koester had noted that the diseased muscle had been almost entirely replaced by fibrous tissue, Volkmann had interpreted the changes as inflammatory, Mikulicz had designated the changes as fibrous myositis, and Kader had stated that the changes are due to hematogenous spread of infection. In the same year, Fitz Simmons [20] stated that pathological study of excised portions of contracted muscles had shown the waxy degeneration of Zenker which had been described as a sclerotic interstitial myositis culminating in hardening of the muscles with subsequent shortening. He also gave the following reasons for considering the theory of Stromeyer to be implausible: (1) rupture of muscle in other parts of the body is never followed by myositis and contracture; (2) Heller showed it was impossible to cause myositis and contracture in animals except by injections of actual pyogenic organisms; (3) most of the infants with torticollis seen after birth show no evidence of hematoma or injury; and (4) in most instances hematoma of the sternocleidomastoideus is not followed by torticollis. In this same article he pointed out that the scalenus anterior, trapezius, and splenius capitis are frequently involved in contracture conditions affecting the sternocleidomastoideus.

Three years later, in 1918, Bevan stated that this condition represents a type of fibrous degeneration in which the muscle cells are replaced by connective-tissue cells, resulting in contracture. In 1921, Albee stated that this condition is usually limited to the sternocleidomastoideus muscle but that in long-standing severe cases, the platysma, the scaleni, and the spelini may also be shortened.

In 1923, Jones and Lovett said that in torticollis the sternocleidomastoideus contains abnormal amounts of fibrous tissue. This scarlike fibrous tissue may occur in patches throughout the muscle or in severe cases it may largely replace the muscular tissue. There is also adaptive shortening of the other soft parts of the neck. These findings would seem to indicate the presence of fibrous myositis and perimyositis. Clark, in 1925, wrote that as a result of the pathological studies made by Bouvier, Krogius, Volkmann, Mikulicz, and others, the character of the muscle change had been determined. He stated that there is a substitution of fibrous-connective tissue for the muscles and that sometimes the replacement is almost complete, resulting in the formation of a fibrous band. The muscle fibers which are left lose their cross striations.

In 1929, von Lackum reported that in three of four cases the sternocleidomastoideus muscle was apparently normal above and below the site of injury; in one of these cases, however, the scar ran into both divisions of the insertion. In the fourth case the hemorrhage or injury extended the entire length of the muscle, although in the outer aspect there was still what appeared to be normal muscle tissue. In all four cases, muscle tissue was distributed through the mass of scar, becoming more extensive in the muscle mass or tumor as the muscle was approached at either end or, in one case, at one side. The fibers in the neck proper showed severe degeneration, apparently as a result of pressure. Von Lackum added that a closer and more extensive study of the muscle in the early period, several months after birth, may solve the problem of etiology and make possible the prevention of the lesion. He stated that microscopic sections showed degenerating muscle fibers in the midst of relatively dense scar tissue. The muscle fibers were apparently replaced by connective tissue. Connective tissue and dense scar tissue composed the mass removed at operation. He noted the homogenous appearance of some muscle fibers and the presence of vacuoles in other muscle fibers, indicating degeneration.

In 1930, Middleton, in a survey of ninety cases, wrote that the torticollis condition seen in later childhood has the same clinical and pathological appearance as that seen in infancy and that it would appear rational to expect that all cases are attributable to a common cause. The sternocleidomastoideus tumor of infancy is usually present at one to two weeks after birth; it first appears as a spindle-shaped swelling occupying the position of the sternocleidomastoideus muscle, occasionally involving only the sternal head but frequently involving both sternal and clavicular heads. The uppermost portion of the muscle close to the mastoid process is seldom, if ever, affected. The enlarged muscle is hard and feels cartilaginous when touched. The tumor is present for two or three months and then is gradually absorbed, disappearing four to six months after birth. It is not uncommon for a child to show a mild degree of temporary torticollis while the tumor is at its fullest development. In some cases a true torticollis begins to develop while the tumor is diminishing in size, the head being drawn over to one side as the tumor is absorbed.

Grossly, the tumor appears to be composed of glistening fibrous tissue and resembles a soft fibroma. Microscopic study shows that it consists of young and cellular fibrous tissue in which are remnants of the original muscle fibers. Many of these fibers have no nuclei or vacuolation and are undergoing degeneration. Microscopic study of the sternocleidomastoideus tumor in a child about eight years old with fully developed torticollis reveals that in its terminal stage the tumor has the following characteristics. There is no degenerating muscular or young fibrous tissue; instead there are swathes of adult, non-cellular fibrous tissue, with scattered collections of muscle fibers. These fibers, although smaller than normal and varying somewhat in size and outline, are living and healthy and show none of the stigmata of degeneration.

Although the torticollis is the result of the absorption of the tumor in the infant, it usually does not become apparent for three or four years. This is because the neck of the infant does not begin to assume the proportions of a "child" until this time. When growth does commence, the muscle substance on the affected side which has been partly replaced by abnormal tissue will not elongate to the same extent as normal muscle. Thus, the muscle lags behind in growth and becomes relatively shortened, producing the classic deformity.

Middleton described a number of pathological changes which may appear in the skeleton in association with congenital torticollis. One such change is that an exostosis may develop in the clavicle when there is fibrosis in the clavicular head of the muscle. Exostosis is never seen at the sternal attachment because in this region the fibrosed muscle fibers are separated from the bone by the normal fibrous tissue of insertion. In the clavicular head, however, the scar tissue comes into direct contact with the bone. Apparently the new-bone formation is caused by the minute recurring traumata which are inflicted upon the subperiosteal layers of the bone through the shortened muscle.

Pathological changes occur especially in the skeleton of the face and skull. There is well marked asymmetry of the bone in the skull, and the eyebrow on the side of the shortened muscle tends to slope downward. The portion of the face below the level of the eye appears to be shorter from above downward and to be wider from side to side than the corresponding portion of the normal side. On the affected side the frontal eminence is flattened and there is a well marked bulge in the occipital region, while on the other side, the eminence is unduly prominent and the occipital region is rather flat. In short, the vault of the skull has been thrown back on the affected side and pushed forward on the opposite side. The deformity of the skull varies according to the severity of the cervical curve as long as growth continues; thus the facial asymmetry tends to diminish gradually after surgical correction of the deformity. If treatment is undertaken early, all traces of asymmetry may disappear.

In 1931, Holloway reported several cases. In one case the patient was operated upon

twelve days after birth, which is the earliest time of operation recorded in the literature. In this case the muscle fibers of the tumor were found to have been replaced by fibrous tissue and study of sections showed that there were no blood cells. Another patient was operated upon five weeks after birth; in this patient thrombus formation was found in addition to fibrous changes. Still another patient, operated upon when seven weeks old, showed even more marked fibrosis.

In 1934, Hough quoted Middleton as saying that excision of the tumor has definitely proved that it is composed of young cellular fibrous tissue containing scattered degenerative muscle fibers. Hough also wrote that the first reports of cases of torticollis in this country were made by John Warren of Boston in 1841 and John Brown of Boston in 1842.

Chandler and Altenberg, in 1944, stated that in their series gross pathological study had showed a fusiform swelling of the entire muscle including both sternal and clavicular heads. The swollen muscle was from two to six centimeters in length and from one to one and one-half centimeters in width and felt firm, fibrous, and, at times, cartilaginous. On section, the tissue appeared white and glistening. In an older child, after disappearance of the tumor, the muscle was found to have been replaced by a dense fibrous tendinous band. Microscopic study showed no evidence of hematoma. Instead it showed almost complete disappearance of the muscle cells which had been replaced by dense fibrous tissue. The few muscle fibers remaining were in varying stages of degeneration, showing swelling, vacuolation (some with many nuclei), absence of striations, and changes in staining characteristics. In some, calcification was present, and in all there were great masses of young fibrous tissue and fibroblasts. Chandler and Altenberg further reported that as the patient grows older and the tumor begins to disappear, more and more of the muscle cells vanish and the fibrous tissue becomes dense and acellular so that finally all that remains is dense, inelastic hyaline connective tissue which contains nuclei arranged in parallel rows and which thus resembles tendon.

Reye, in 1951, reported autopsy findings in infants one, three, and five months of age with congenital muscular torticollis. He was the first to relate studies of longitudinal sections. These studies revealed the presence of multinucleated muscle masses with hyaline degeneration. They also revealed that there was a regular arrangement of the fibrous tissue that replaced the affected muscle and that there was no line of demarcation between this fibrous tissue and the tendinous attachment.

In a textbook concerning diseases of muscle, Adams and associates stated that giant cells have been seen in the muscles of patients with congenital muscular torticollis. They described these cells as masses of sarcolemmic nuclei and interpreted their presence as representing early attempts at regeneration of muscle fibers. In 1955, Kiesewetter and associates reported that in 85 per cent of the cases they had reviewed, the muscle bundles were replaced by fibrous tissue, varying degrees of atrophy being present in the surviving muscle fibers. Dense collagen was found in 20 per cent of the cases but was not conspicuous, suggesting that the lesions were not of long duration. Evidence of degeneration and atrophy of striated muscle was seen in all cases.

Some experimental work regarding changes in muscle following trauma of various kinds has been mentioned previously. Brooks in 1922, studied the pathological changes occurring in muscle as a result of disturbances in circulation. He did his work on dogs. Among his findings was the fact that when the vein leading from a muscle was completely occluded but the artery was left intact, pathological changes in the muscle consistently resulted. These changes included hemorrhage, oedema, degeneration of muscle fibers, acute inflammation, and fibrosis of the muscle. The surrounding tissues were also involved in the fibrosis process, so that eventually the muscle became embedded in a fibrous tissue mass.

Brooks also found that permanent obstruction of the arterial supply of an extremity may result in gangrene and necrosis but will not cause fibrosis and substitution of the

muscles with fibrous tissue. Simple hermorrhage into the muscle with or without interference of arterial or nerve supply did not cause the fibrosis or changes which were seen following venous obstruction.

Jepson, in 1926, in an experimental study produced fibrotic changes in the muscles of animals by venous occlusion. Middleton did similar work a little later and arrived at essentially the same conclusions as Brooks.

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Mono-Articular Brucellar Arthritis

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Brucellosis, otherwise known as undulant or Malta fever, is an infection due to brucellar organisms. It is primarily a disease of animals but is frequently transmitted to man, in whom it produces attacks of recurrent fever. Generalized joint pains commonly accompany the fever; the pains characteristically shift from joint to joint and are a late rather than early manifestation of the disease. In about 10 per cent of the cases, arthralgia constitutes the chief symptom; in these cases objective physical signs of bone or joint involvement are rarely found.

Mono-articular arthritis is occasionally the dominant symptom of brucellosis. In such cases the diagnosis may easily be overlooked unless the possibility of brucellosis is entertained, for mono-articular brucellar arthritis has no specific clinical features.

Two cases of mono-articular brucellar arthritis are presented here. In the first case *Brucella melitensis* was isolated from the joint fluid, and in the second case the acute local manifestations justified the performance of arthrotomy of the joint.

CASE 1. A twenty-eight-year-old man was admitted to Hadassah Yassky Negev Hospital, Beersheba, on September 20, 1955, complaining of pain and swelling of the right knee. He had not felt well for two weeks previously and suffered from mild generalized joint pains. Three days prior to his admission to the hospital, the right knee joint had become swollen. Upon examination the patient did not appear to be seriously ill. His temperature was 99.8 degrees Fahrenheit and his pulse was 110. There was a marked synovial effusion of the right knee joint causing mild restriction of knee motion. The joint was not tender to pressure, there was no local elevation in temperature, and there were no signs of local inflammation. Aspiration of the joint produced clear yellow synovial fluid. The spleen was palpable below the costal margin, and enlarged lymph glands were felt in both axillae and groins. A complete blood count showed a red-cell count of 4,150,000 per cubic millimeter and a white-cell count of 7,900 per cubic millimeter (differential count: 65 per cent neutrophils, 28 per cent lymphocytes, 3 per cent eosinophils, and 4 per cent monocytes). The blood hemoglobin was eleven grams per 100 cubic centimeters; the sedimentation rate (Westergren) was thirty-two millimeters in one hour and sixty millimeters in two hours; the serum urea was eighteen milligrams per 100 cubic centimeters; and the blood sugar was ninety-two milligrams per 100 cubic centimeters. The results of the Widal and Kahn tests were negative, and the findings of the urinalysis were normal.

The patient lived in an area where brucellosis was prevalent, and this gave rise to the suspicion that the synovitis of the knee joint might be due to a brucellar infection. Blood taken two days after the patient's admission to the hospital showed no brucellar agglutinins, but culture yielded *Brucella melitensis*. Synovial fluid taken from the knee on the same day similarly showed no agglutination but yielded *Brucella melitensis* on culture. A week later, tests of the synovial fluid revealed agglutination of brucellar organisms in a titer of one to fifty. Four days later brucellar agglutinins in a titer of one to 400 were found in the blood serum. The patient received 0.5 gram of streptomycin and 1.0 gram of terramycin daily, and both temperature and knee swelling rapidly subsided. After seventeen days of hospitalization, the patient returned to work and since then has had no further disability. A letter received from him fifteen months after he left the hospital confirms that he has had no recurrence of any trouble referable to his right knee.

This was initially a typical case of brucellosis, the patient not appearing seriously ill but suffering from general malaise and migratory joint pains. The unusual presenting sign was a considerable synovial effusion into the right knee joint.

Significant in this case was the fact that positive results were concurrently obtained from cultures of samples of synovial fluid and blood even though in these same samples no brucellar agglutinins were found. It is noteworthy that the synovial fluid was the first to show a positive agglutination reaction. The blood agglutination reaction was delayed, and a diagnostic titer was not present until eleven days after the positive culture results had been obtained.

Although the behavior of brucellar agglutinins is unpredictable, absence of these agglutinins during the relatively lengthy positive-culture phase of the disease is unusual.

FIG. 1

Case 2. Roentgenogram of both hips. No definable soft-tissue swelling or abnormality is apparent in either hip. In the left hip there is a suggestion of an increase in the joint space.

CASE 2. A nine-year-old girl with acute coxitis was admitted on an emergency basis to the Orthopaedic Department of the Rothschild Hadassah University Hospital on November 1, 1954. The patient had complained of abdominal pain and fever eight days previously, but after a few days the symptoms had subsided. On admission the chief complaint was severe pain in the left groin.

Examination revealed a child with a temperature of 101.3 degrees Fahrenheit, a pulse of ninety-six, a respiration rate of twenty-four, and a blood pressure of 110/65. She was unable to sit, and all movement was painful. There was marked spasm of all muscles around the left hip, and no active or passive motion was obtainable at this joint. A general physical examination did not reveal any abnormality. A complete blood count showed a red-cell count of 4,360,000 per cubic millimeter and a white-cell count of 5,900 per cubic millimeter (differential count: 40 per cent neutrophils, 1 per cent band forms, 52 per cent lymphocytes, and 7 per cent monocytes). The blood hemoglobin was 11.2 grams per 100 cubic centimeters; the serum urea, thirty-five milligrams per 100 cubic centimeters; and the blood sugar, eighty-six milligrams per 100 cubic centimeters. The reactions to the Wassermann, Kahn, and Widal tests were negative; the results of the blood culture for typhoid were negative; and the findings of the stool examination were normal. The blood sedimentation rate (Westergren) was eighteen millimeters in one hour and forty millimeters in the second hour. The findings of the urinalysis were normal, and the urine culture was sterile. Roentgenographic study of the hip revealed no abnormality (Fig. 1). A tentative diagnosis of acute arthritis was made, and treatment with aureomycin (150 milligrams four times daily) was instituted.

Despite treatment the patient's condition worsened. The toxaemia continued, and the fever persisted, the patient's temperature being between 101 and 102 degrees Fahrenheit. The localized severe hip pain and muscle spasm continued unabated. An attempt to aspirate fluid from the hip joint was unsuccessful. Notwithstanding the relative leukopenia, septic arthritis of the hip joint was suspected. Four days after the patient's admission, arthrotomy of the hip was performed. Exploration showed the hip to be distended, and six cubic centimeters of serous fluid which had been under tension was evacuated from the joint. Following arthrotomy, the localized hip pain and spasm disappeared. Active and passive hip motion was restored. The localized hip symptoms were apparently due to the distention caused by the serous accumulation. Culture of the joint fluid was sterile, and biopsy of the synovial membrane did not reveal any significant pathological condition (Figs. 2 and 3).

Examination of the blood serum on November 5, 1954, revealed brucellar agglutinins in a titer of one to 1,600, and blood culture yielded *Brucella melitensis*. Treatment was continued, three grams of sulphadiazine and 0.6 gram of aureomycin being given daily for thirteen days. The operative wound healed without incident, and after thirty days of hospitalization, the patient was discharged.

Five weeks after discharge the child complained of fatigue and headache, and her temperature rose to 104 degrees Fahrenheit. On January 4, 1955, she was readmitted to the hospital. This time, in spite of the high fever, the patient did not seem to be seriously ill. Enlarged lymphatic glands were felt in the left supraclavicular fossa, and the spleen was palpable four centimeters below the costal margin. On this occasion there were neither symptoms nor signs of any joint involvement. The results of blood culture were again

positive for *Brucella melitensis*, and a brucellar agglutination test revealed a titer of one to 400. Terramycin (one gram daily) and streptomycin (0.5 gram daily) were given, and after one month's hospitalization the patient was discharged.

The patient was re-examined in December 1956. There had been no further recurrences, and the hip joint showed a full range of motion. Roentgenographic study of the joint showed normal findings. Blood-serum examination revealed that there were no brucellar agglutinins, either complete or incomplete, and the blood culture was sterile.

FIG. 2

Case 2. Photomicrograph of material from the synovial membrane of the hip joint. The synovial membrane is moderately vascular (hematoxylin and eosin, × 100).

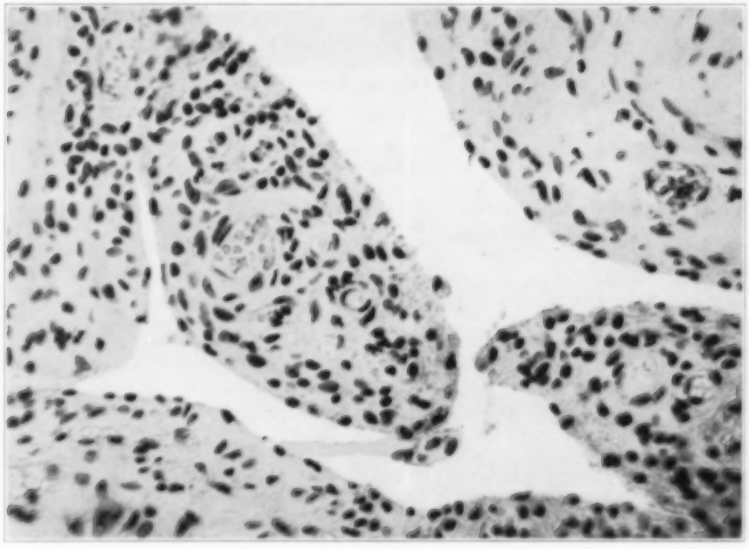

FIG. 3

Case 2. Photomicrograph of material from the synovial membrane of the hip joint (hematoxylin and eosin, × 350).

In this case the dominating symptoms and signs were those of acute arthritis of the hip joint, simulating acute septic arthritis. The clinical findings were of such severity as to justify arthrotomy of the hip joint. Synovial fluid under tension was released from the joint, following which the local arthritic manifestations subsided. *Brucella melitensis* was twice isolated from the blood stream, and antibodies were present in high titer. Culture of the synovial fluid produced negative results. Testing of the synovial fluid for agglutination reaction was, unfortunately, not done. Examination of the joint by the naked eye and microscopic examination of the synovial membrane did not show any pathological changes. The relapse provoked no joint involvement.

DISCUSSION

The diagnosis of brucellar arthritis is difficult, and the frequent absence of detectable physical abnormalities must be stressed. The diagnosis should be considered whenever there is arthritis of a major joint which cannot be explained on any other basis. Roentgenographic examination does not contribute, and inspection of the joint and biopsy of the synovial membrane may likewise fail to establish the diagnosis. Usually the serum agglutination reaction is relied upon for the diagnosis, but this may be negative in the early stages of the disease. The synovial fluid may provide contributory diagnostic evidence in the form of positive results from culture and a positive agglutination reaction. Coventry and associates noted that isolation of Brucella is more likely to succeed when tissue rather than synovial fluid is sent for culture. Brucellar organisms are known to develop intracellularly and are freed only intermittently into the body fluids.

Little is known of the pathological changes which occur in brucellar arthritis. The review of Sprunt and McBryde on the morbid anatomy of brucellosis in man gives no information on the macroscopic or microscopic articular changes. Biopsy of the synovial membrane of the hip joint in Case 2 did not reveal any pathological changes.

There are few reported cases of mono-articular brucellar arthritis and even fewer have been proved bacteriologically. Coventry and associates were able to find only four cases of brucellar coxitis in the literature.

The burden of the diagnosis lies upon the bacteriologist. Unless the diagnosis is anticipated, it is unlikely that the necessary tests will be initiated. Failing an anticipation of brucellosis, the diagnosis may all too often be missed.

NOTE: The authors are indebted to Dr. E. Lehman, Medical Director of the Hadassah Yassky Negev Hospital, Beersheba, for permission to publish Case 1.

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Massive Familial Tarsal Synostosis

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Massive tarsal synostosis, appearing bilaterally in two successive generations of one family, is an occurrence unusual enough to report. A review of the literature failed to uncover any similar cases. Congenital bilateral fusions of the talus, the navicular, the cuboid, the middle and lateral cuneiforms, and the second, third, and fourth metatarsals were noted in a mother and her two children. A questionable history of similar involvement in her father was obtained.

In 1879, Anderson, an anatomist in Belfast, Ireland, described a dissection in which bilateral talonavicular fusions were noted. Subsequently, single cases of bilateral congenital talonavicular synostoses were reported [8, 10]. In 1944, Boyd contributed to the literature the reports of four more cases of bilateral talonavicular synostosis, three of which occurred in successive generations of the same family. In 1951, Austin reported symphalangism in the hands and feet and talonavicular and calcaneocuboid synostoses in a

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 1. Lateral view of the right foot, showing synostosis of the talus, the navicular, the cuboid, the middle and lateral cuneiforms, and the second, third, and fourth metatarsals.

Fig. 1-B: Anteroposterior view in standing position, showing dorsal bunions over the first metatarsophalangeal joints and mild supination of the fore part of the feet.

FIG. 1-C

FIG. 1-D

Fig. 1-C: View of both feet in standing position twelve years after operation, showing the prominent dorsal bunions at the heads of the first metatarsals.

Fig. 1-D: View of both feet twelve years after operation. Note the medial convexity of both feet with prominent thickening at the bases of the fourth and fifth metatarsals.

FIG. 1-E

FIG. 1-F

Fig. 1-E: Anteroposterior roentgenogram of the left foot twelve years after operation.
Fig. 1-F: Anteroposterior roentgenogram of the right foot twelve years after operation.

man twenty-one years old and in his older brother. According to the patient's history, his mother, maternal uncle, and maternal grandfather were similarly affected.

Wagoner, in 1928, and Mahaffey, in 1945, each described a case of bilateral congenital fusion of the calcaneus and cuboid.

Shands and Wentz reviewed 850 roentgenograms of children's feet which were made for the clinical demonstration of various deformities. Six of these patients showed fusion of two or more tarsal bones. Roentgenograms of one patient showed bilateral fusion of all the tarsals except the first cuneiform.

Several authors have described calcaneonavicular and talonavicular coalition, particularly with reference to peroneal spasm [4, 5, 6, 7, 12].

CASE REPORTS

CASE 1. F. M., a boy eight years old, complaining of "stiff feet," was examined on July 15, 1941. His mother had noticed an inversion of the feet when he walked. Early fatigue was a major complaint. Examination revealed mild varus of both heels, supination of the fore part of the feet, and fixed plantar flexion of the outer four metatarsals with plantar prominence of the metatarsal heads. The first metatarsals were elevated in relation to the outer four metatarsals, and a dorsal bunion was present at both first metatarsophalangeal joints. No weight-bearing was performed by the first metatarsal heads. With the patient under general anaesthesia, inversion and eversion mobility in both feet was found to be restricted to 15 degrees. Roentgenograms revealed bilateral congenital synostosis of the talus, the navicular, the cuboid, the second and third cuneiforms, and the second, third, and fourth metatarsals. On August 7, 1944, bilateral mid-tarsal osteotomy was performed. Good correction of the supination deformity was obtained, but plantar flexion of the outer four metatarsals persisted. At follow-up examination twelve years after the operation (December 1956), the patient had no pain in his feet. He was able to walk miles without difficulty, he wore standard 8½ E shoes, and his only complaint was dorsal prominence of the first metatarsal heads. Examination at this time revealed bilateral heel valgus of 5 degrees and elevation of the first metatarsals with supination producing prominent dorsal bunions. Ankle motion was from 80 to 130 degrees bilaterally; there was no demonstrable subtalar motion.

FIG. 2-A

FIG. 2-B

Fig. 2-A: Case 2. Lateral view of both feet in standing position.
Fig. 2-B: Lateral view of the feet four months after operation. Note the improved relationship of the first metatarsal to the outer metatarsals and the decreased supination of the fore part of the feet.

FIG. 2-C

Oblique roentgenogram of the right foot showing metatarsocuneiform coalition.

CASE 2. M. M., the fourteen-year-old sister of F. M. (Case 1), presented changes similar to those noted in her brother. She complained of fatigue and pain in the anterior portions of both feet, and a callosity was present beneath the heads of both fifth metatarsals. Roentgenograms revealed bilateral congenital synostosis identical to that seen in the roentgenograms of her brother, but with greater fusion of both first metatarsocuneiform articulations. Bilateral mid-tarsal osteotomy was performed in August 1956. The follow-up

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 3. Lateral view of the right foot. Findings were identical to those in her daughter.
Fig. 3-B: Anteroposterior view of both feet in standing position.

period of this patient is too short for final evaluation of the clinical result. When the patient was examined in December 1956, four months after the operation, 10 degrees of heel varus was noted in the left foot and 5 degrees in the right. Elevated first metatarsals, less prominent than those noted in the patient's brother, were present. Prominent pads on the plantar aspects of the bases of the fourth and fifth metatarsals were noted bilaterally. The patient reported occasional ache in the right foot. She wore standard 5 B shoes with one-quarter inch outside sole wedges.

Case 3. M. M., the forty-six-year-old mother of the foregoing two patients, first noted pain and early fatigue in the anterior region of both feet when she was eighteen years old. Clinical and roentgenographic examinations revealed findings identical to those in her daughter.

As far as could be ascertained, there had been no similar involvement of the feet in any other member of the family during the previous three generations. No intermarriage was known to have taken place.

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Osteogenic Sarcoma of the Tibia with Pulmonary Metastasis

Report of a Case with Ten-Year Survival *

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This case is a noteworthy instance of prolonged survival and apparent cure in a case of osteogenic sarcoma in which the original lesion of the tibia was treated by amputation and a metastatic focus subsequently appearing in a lung was treated by lobectomy. The pulmonary metastasis presented itself three years after the amputation. Shortly thereafter that lesion was excised, and the patient has remained well seven years after the lobectomy. The diagnosis of osteogenic sarcoma was established by examination of a biopsy specimen from the tibial lesion and was confirmed by anatomical study of tissue from the amputated bone. These examinations were performed by Dr. Henry L. Jaffe of the Hospital for Joint Diseases, New York City. The tissue from the metastatic pulmonary focus was established as representing an osteogenic sarcoma by Dr. John L. Tullis of the New England Deaconess Hospital, Boston.

Fig. 1

Roentgenograms made May 3, 1945, showing oval area of rarefaction in the lower third of the left tibia.

E. H., a girl seventeen years old, was first seen May 3, 1945, complaining of pain in the left leg of five months' duration. At the time of onset, the pain was intermittent and was relieved by bed rest. One month before the first examination she began to limp; the pain, which was localized in the lower third of the left tibia, became continuous and was not relieved by rest in bed.

When examined, the patient walked with a limp on the left side. There was no abnormality in contour of the left lower extremity, and motions of the left knee and ankle joints were complete and painless. There was local elevation in temperature and exquisite tenderness at the junction of the middle and distal thirds of the left tibia. The inguinal glands were neither enlarged nor tender. Roentgenograms (Fig. 1) made on the day of examination showed an oval expanding area of rarefaction in the lower third of the left tibia. The anteromedial cortex was thinned and partially eroded. Roentgenograms of the chest showed no pulmonary metastasis, and a general skeletal survey showed no abnormalities relative to any of the other bones. The remainder of the clinical study of the patient revealed nothing remarkable.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, February 2, 1956.

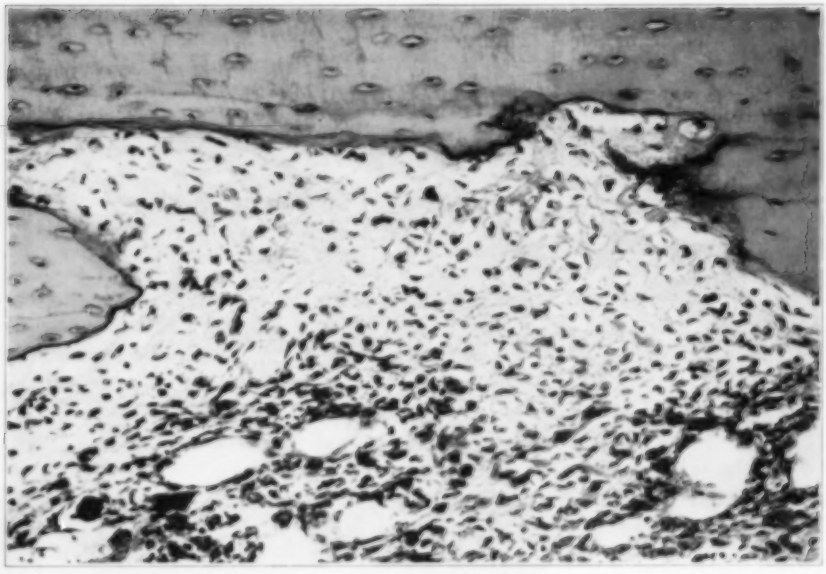

FIG. 2-A

Photomicrograph (× 114) showing osteogenic sarcoma of the tiba. The cortical bone is being eroded by tumor.

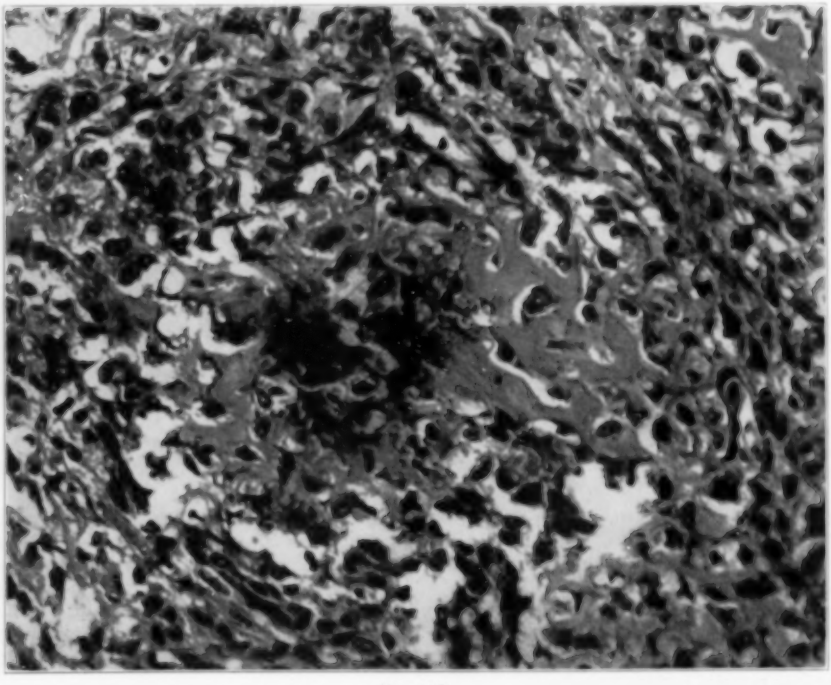

FIG. 2-B

Photomicrograph (× 250) showing osteogenic sarcoma of the tibia. Note the pattern of the tumor tissue with a focus of beginning tumor bone formation.

FIG. 3-A

FIG. 3-B

Fig. 3-A: Roentgenogram made November 10, 1948, showing tumor shadow in the right upper lobe of the lung.
Fig. 3-B: Roentgenogram made November 17, 1948, showing the tumor shadow.

A biopsy of the left tibia was performed July 6, 1945. When the lesional area was exposed, it was found that the periosteum was intact, but that the underlying cortex was thinned. Inside the medullary cavity soft reddish-gray tumor tissue intimately adherent to the inner surface of the cortex was observed.

Microscopic examination (Figs. 2-A and 2-B) of the tissue removed revealed that the outer surface of the cortex was covered with periosteum showing areas of increased cellularity and vascularization. From the

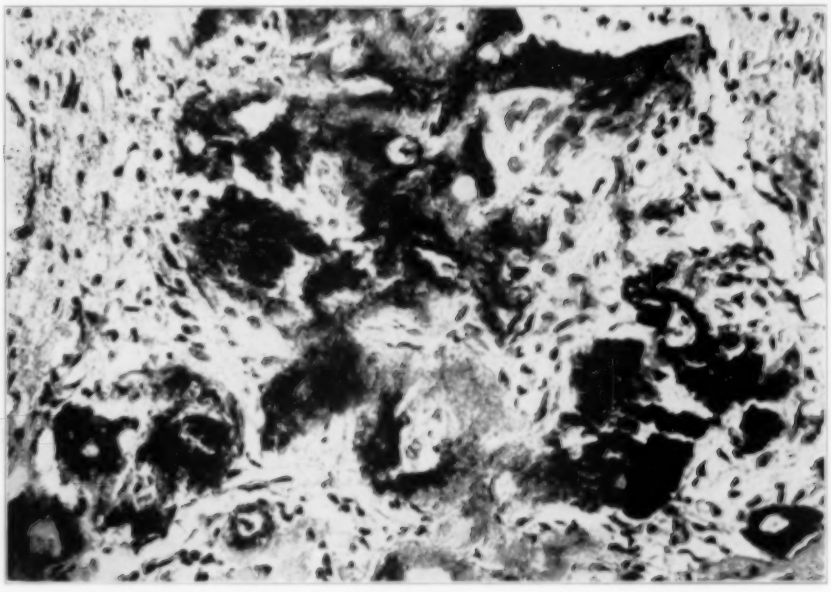

FIG. 4-A

Photomicrograph (× 114). Metastatic lesion of the lung from osteogenic sarcoma of the tibia. There is calcification and ossification of tumor tissue.

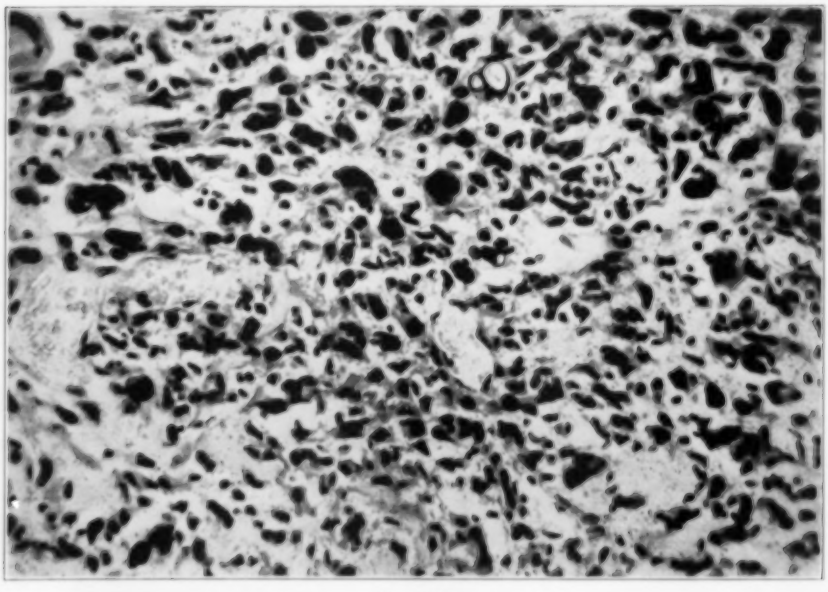

FIG. 4-B

Photomicrograph (× 230). Metastatic lesion of the lung has tumor cells with hyperchromatic nuclei.

FIG. 5

Roentgenogram made November 5, 1955, shows no evidence of recurrence of metastasis. The surgically removed sections of the fifth and sixth ribs have not regenerated.

periosteum a number of blood vessels penetrated into the bone. Fragments of tumor tissue adherent to the inner surface of the cortex were eroding its endosteal surface. The tumor tissue was rather cellular and while many of the cells were spindle-shaped, others were more or less round. In places some of the cell nuclei were surrounded by lacunae. Here and there throughout the lesion one could observe intercellular collagenization and calcification, and occasional sarcoma giant cells.

The postoperative course was uneventful and the wound healed *per primam*. Amputation was advised but refused by the patient; she was discharged from the hospital on July 24, 1945. She was free from pain for one month; examination then revealed a bulging tumor in the region of the biopsy incision. The circumference of the left calf was one-quarter of an inch greater than that of the right. Roentgenographic examination of the chest showed no evidence of metastasis. On October 1, 1945, a mid-thigh amputation was performed.

The specimen was a left lower extremity terminating about six inches above the knee. Located on the anteromedial surface of the tibia at about the junction of the middle and lower thirds was a soft bulging tumor measuring ten by seven centimeters. After sectioning, it was found that the tumor was hemorrhagic and that it extended down to the medullary canal of the tibia. There were also several firm foci of tumor tissue which were firmer than the rest, but which were, however, soft and pinkish-white. There was no involvement of the fibula. Microscopic examination revealed that the tumor tissue was similar to that of the biopsy specimen, except that it was more uniform in appearance and was oedematous. Many of the tumor cells showed irregular, hyperchromatic nuclei and elongated, pink cytoplasm. Sarcomatous giant cells were fairly frequent. The intercellular matrix was pink and fibrillar. The tumor was well supplied with blood vessels, many of which were wide and filled with blood. Between the tumor cells there were scattered polymorphonuclear leukocytes, particularly near the areas of tissue necrosis. Occasional areas of hemorrhage were seen.

The patient was discharged from the hospital October 14, 1945, walking with the aid of crutches. A prosthesis was fitted in February 1946.

Follow-up examinations were made at six-month intervals. On each of these occasions, routine roentgenograms showed no pulmonary metastasis. The patient was symptom-free until November 1948 (three years after amputation), when she first noted a morning cough which she attributed to smoking. She had lost four pounds since the previous examination of April 1948. A routine chest roentgenogram made on November 10, 1948 (Fig. 3-A), and a right anterior oblique postero-anterior roentgenogram made on November 17, 1948 (Fig. 3-B), showed a tumor shadow in the right upper portion of the chest laterally. Skeletal roentgenograms failed to reveal any other metastatic lesions. The patient was referred to Dr. R. H. Overholt.

Operation was performed by Dr. Overholt at the New England Deaconess Hospital, November 24, 1948. The tumor measured five by four by three centimeters and occupied the free edge of the right upper lobe bordering the major fissure. The tumor was roughly spherical in shape, semifluctuant, and was adherent to the pleura under the fourth rib. The pleura along the surface of the medial basal segment was thickened in the area of contact with the tumor. Several small black subpleural nodules were found along the mediastinal surface of both the lower and upper lobes. These were removed for frozen sectioning and were found to contain only lymphatic tissue. The mediastinal lymph nodes were free of tumor. A lobectomy was then performed.

The pulmonary specimen, as described by Dr. Tullis, consisted of:

1. Three tiny previously sectioned tissue fragments measuring in aggregate 0.7 centimeter in the greatest diameter.

2. A right upper lobe of the lung weighing eighty grams. Externally, the pleura was smooth and light red. A dark red, multinodular, cystic lesion, measuring five by four by three centimeters, occupied the postero-inferior angle. After fixation, section through the lobe revealed the nodule to be multicystic and hemorrhagic with thin, glistening, gray septa. There was one firm, glistening gray nodule centrally placed which measured approximately one centimeter in diameter. Section through this nodule revealed a gray, homogenous surface containing calcific granules.

Microscopic examination (Figs. 4-A and 4-B) revealed that the tumor was largely composed of hyperchromatic pleomorphic, spindle-shaped cells growing in a rather dense pavement pattern. Many of the cells were binucleated. The nuclei were hyperchromatic, and thin chromatin was distributed in large clumps. The cytoplasm was scanty and acidophilic. Numerous giant cells were scattered throughout the section. Mitoses were moderately frequent. Irregular vascular spaces and areas of hemorrhage were present. The tumor did not appear to invade the blood vessels. In one small central area there was evidence of beginning tumor bone formation with surrounding tumor osteoid formation. Small areas of necrosis and a few leukocytes and lymphocytes with a few plasma cells were scattered throughout the tumor.

The postoperative course was uneventful and the patient was discharged from the New England Deaconess Hospital December 8, 1948. She has worked steadily as a laboratory technician since January 1949. She was last examined November 5, 1955. Roentgenographic examination of the chest (Fig. 5) made at that time showed no evidence of recurrence of a metastatic lesion. The surgically removed sections of the fifth and sixth ribs had not regenerated.

DISCUSSION

Dr. C. Howard Hatcher, Chicago, Illinois: Bone sarcoma considered from the standpoint of curative treatment is generally a discouraging subject. Dr. Goldenberg's report, however, justifies a more optimistic attitude; he has presented a case of a highly malignant osteosarcoma, followed by a solitary metastasis to the lung, which was probably permanently cured. The patient was treated by surgical removal of both the primary tumor and the metastasis. Generally we expect that patients with bone sarcoma whose roentgenograms show the presence of a pulmonary nodule will soon succumb to widespread metastasis. However, sarcomata which form a great deal of bone may occasionally follow a peculiar course in which the primary tumor grows very large before metastases appear. Even metastatic nodules may remain under control for a comparatively long time, thus giving opportunity for their successful surgical removal.

In connection with Dr. Goldenberg's report, I would like to mention two patients observed at the University of Chicago Clinics. As did Dr. Goldenberg's patient, each had a highly malignant and intensely ossifying neoplasm which was eradicated surgically. Roentgenographic evidence of pulmonary metastasis followed. Excision of a large osteosarcoma of the distal end of the right femur was performed on a girl of seventeen years. One year later, there was roentgenographic evidence of a solitary metastatic nodule in the right lung. Since there were no symptoms, however, no treatment was given. The nodule grew for two years until it occupied most of the middle lobe, but no other nodules appeared. Pneumonectomy was performed and four years later the patient was well and without evidence of a recurrence of the tumor. Histological examination of the pulmonary mass showed that although there were areas of living malignant tumor, the larger part of the nodule had been replaced by bone which was so mature that it had even formed hematopoietic marrow.

The second patient, a seventeen-year-old boy, had an osteosarcoma of the proximal end of the tibia

which was treated by mid-thigh amputation. One and one-half years later, there appeared in the roentgenograms of his chest two nodules of bony density situated in the left upper lobe of the lung. Twenty-four years later, the patient was well although roentgenograms still showed the dense nodules.

Dr. Goldenberg's presentation is concerned with spread of tumors through the body. Although knowledge of this subject is incomplete, it has long been recognized that bone sarcomata spread mainly by the hematogenous route. Bones seem to have no important lymphatic channels; it is uncommon indeed to find regional lymph-node involvement by tumors or infections which are primary in bone. The route of tumor cells into the venous circulation frequently can be observed in histological sections. Often tumor thrombi are present in the venules of the reactive fibrous tissue around the advancing margins of the neoplasm. Many times degeneration of tumor tissue leads to cavitation and small-vessel erosion so that tumor spaces become confluent with the vascular network. It seems probable that tumor cells readily escape into the venous circulation. However, their lodgment in distant tissues and their ability to survive and grow determines the pattern of secondary nodules.

Bone sarcoma metastasis to other parts of the skeleton is more common than has been realized in the past. The view that skeletal metastases are rare in sarcoma probably originated before roentgenography, when investigation for evidence of secondary nodules was not easy. It is likely that skeletal-survey roentgenograms made periodically and at autopsy would disclose many instances of spread to other bones.

Although lodgment of tumor cells in the lungs is the most prominent feature of sarcoma metastasis, there is no reason why they cannot pass over into the arterial circulation and spread to other organs. Tumor cells possess amoeboid properties; they can adapt their shapes so as to pass through the capillary network of the lungs. That certain sites are more favorable than others for the lodgment and growth of these metastatic cells is evident. The hematopoietic regions of the skeleton are much more commonly the sites of metastatic growths than are the fatty marrow regions. The spleen, although it is often the site for lodgment of circulating tumor cells, rarely demonstrates viable tumor tissue. While the pattern of distribution of secondary tumors may in part be explained by the mechanics of circulation, there must also be the factor of *favorable soil* which determines their survival and growth.

DISCUSSION

Grade IV Fracture-Dislocation of the Hip

(*Continued from page 1042*)

analogous to that in old, slipped proximal femoral epiphysis, for in hips with that condition vigorous manipulation also generally produces a poor result. In both these conditions, the importance of gentleness cannot be overemphasized. One of the most neglected phases of treatment following hip injury or hip surgery is muscle rehabilitation. You must have a definite plan and take time to properly instruct your patient in detail as to his remedial exercise program. We have repeatedly found that the patient who must use his limb the most in his daily activities during convalescence will invariably obtain the best functional result.

Good managment of these hip injuries depends first and foremost upon prompt diagnosis and immediate reduction. This has become universal teaching among orthopaedic surgeons. It now behooves us to spread this information to the general practitioner, the general surgeon, the internist, the medical student, and even to the layman.

Dr. Philip D. Wilson, Jr., New York, N. Y.: In connection with the cases in this series in which there was painless weight-bearing in the presence of pseudarthrosis, I would like to mention the series of L'Episcopo * in which he performed bone-block arthrodesis in painful hips. In the first case in this series, an extra-articular bone graft had been used; this graft had united with the ilium but not with the trochanter, so that it acted as a block against the femur. The final result was a hip which could bear weight without pain and which had a fair range of motion. In the remaining sixteen cases in this series the procedure that had accidently been followed in the first case was purposely duplicated. L'Episcopo believed that the bone block either deviated some of the load from the faulty hip or prevented painful capsular impingement. It is interesting to note that in the cases in Dr. Pipkin's series with pseudarthrosis, the roentgenographic appearance of the hips and the functional results were similar to those in L'Episcopo's series.

* L'Episcopo, J. B.: Bone Block for Painful Hips. J. Bone and Joint Surg., **20**: 901–911, Oct. 1938.

Eight Cases of Hereditary Bilateral Medial Tibial Torsion in Four Generations*

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Although the clinical importance of tibial torsion is recognized and several excellent studies on this subject have been reported, the lack of agreement within the medical profession regarding the etiology of this condition prompts us to report this interesting pedigree. The medical practitioner of today must be aware that the study of human heredity, although relatively new, has already become an integral part of the physician's education. Medical genetics has a permanent place in clinical investigation.

The adjectives *hereditary*, *congenital*, and *developmental* have various connotations; therefore, it is necessary to understand the sense in which the word *hereditary* is used here. In our investigation, the abnormality under discussion follows a definite type of Mendelian inheritance and is, therefore, under the control of the genes. Hereditary traits controlled by genes may be variable in time and in degree of expression, and frequently they fail to express themselves altogether, even when an individual has the genetic constitution. Another factor to be considered is the pleiotropic action of the gene. Furthermore, the interaction of genes and environment influences the expression of so-called anomalies in living organisms. It is also well known that metabolic insults, dietary deficiencies, and certain disease-producing agents encountered during early development are responsible for certain defects which are more likely to occur in some genotypes than in others.

In a review of the literature [1-11], the authors found that much has been written about deformities of the lower extremities but that very little attention has been given to torsional deformities of the developmental and hereditary type. Most authors conclude that there is an acquired and a congenital type of tibial torsion, in addition to that caused by rickets; the latter now can very easily be ruled out. However, no effort has been made to distinguish between the first two types of tibial torsion on a genetic basis.

According to Kite [5], the rotation test is one way to distinguish between acquired torsion and congenital torsion. (We assume congenital torsion to be the genetically inherited type.) In patients with congenital torsion, the patella can be turned medially and laterally about as far as in the normal child. In patients with acquired torsion, the patella can be turned medially 90 degrees or more, but laterally it can be rolled only slightly past the mid-position. Both the rotation test and roentgenograms are valuable in the examination of sporadic cases when previous family history of this condition is lacking.

CASE HISTORY

Chart I presents four generations in which eight cases of bilateral medial tibial torsion have occurred. The Roman numerals indicate generations, and the Arabic numbers identify individuals. Our attention was directed to this pedigree by the propositus (IV-1).

This white male child was born August 7, 1952, and was first seen in the Out-Patient Department of John Sealy Hospital on August 19, 1954. The patient's history at that time revealed the following: there was a nine-month uncomplicated pregnancy followed by a normal vertex delivery. The child was considered normal at birth. Bowing of the legs was first noticed when the child began to stand, at eleven months of age.

* This research was partially supported by grant No. A-848, National Institute of Arthritis and Metabolic Diseases, the United States Public Health Service.

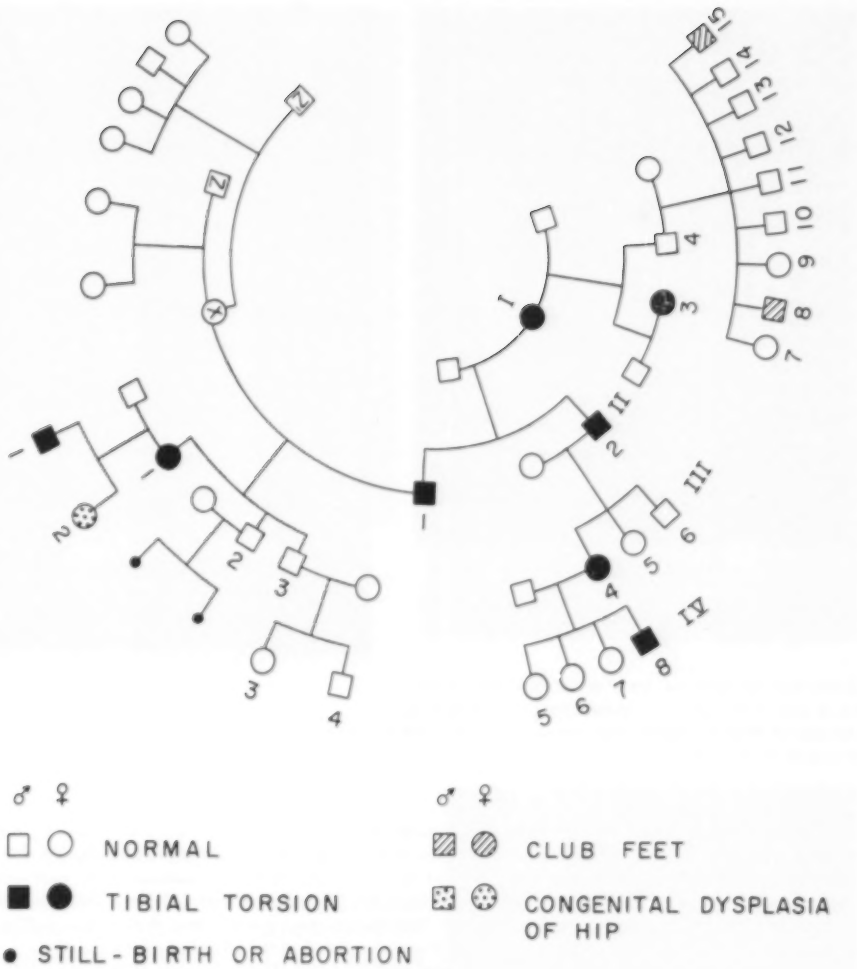

CHART I

Pedigree showing eight cases of hereditary bilateral medial tibial torsion in four generations. The Roman numerals indicate generations, and the Arabic numbers identify individuals. The progenitor, I-1, was married twice, transmitting the trait in both marriages to II-1, II-2, and II-3. II-1 and II-2 married and transmitted the deformity to III-1 and III-4. III-1 and III-4 married, transmitting the deformity to IV-1 and IV-8. X, the mate of II-1, subsequently married twice, Z and Z', with progeny who did not show the deformity. The mate X, therefore, did not carry the dominant gene for tibial torsion.

It was the opinion of the mother that the deformity had become progressively worse. Surgery had been performed when the child was a year old for release of the frenulum linguae.

Examination revealed a rather pale but adequately nourished child. He walked with his feet extremely wide apart, and there was prominent bowing of the lower extremities with intoeing of the feet. Medial tibial torsion was marked.

Roentgenograms revealed bowing of both femora and tibiae (Figs. 1-A and 1-B). The bowing was greater in the tibiae which also demonstrated the torsion.

Blood studies revealed that the serum calcium was 10.1 milligrams per 100 milliliters, the serum inorganic phosphorus was 3.4 milligrams per 100 milliliters, and the alkaline phosphatase was 7.3 Bodansky units.

A diagnosis of hereditary bilateral medial tibial torsion was made.

It was decided not to put the child in braces but to observe him at regular intervals in order to check the progress of the condition with weight-bearing and normal activity. After one year of observation, it was apparent that surgical correction would be the better form of treatment. On March 7, 1956, bilateral

FIG. 1-A

FIG. 1-B

Figs. 1-A and 1-B: Roentgenograms of propositus, IV-1, made eighteen months prior to operation, showing torsion.

derotation osteotomies were performed with Steinmann-pin and plaster immobilization. Rotation through at least 45 degrees was necessary on each side to correct the deformity. Figures 1-C and 1-D show the result of this operation.

Pedigree

Several interviews with the mother of the propositus (III-1), who was twenty-four years old, revealed that the progenitor (I-1) of the anomaly was married twice; the husbands were not related. By her first marriage there were two sons; both were affected (II-1 and II-2). By the second husband there were also two children, a boy and a girl. The girl (II-3) showed the trait. The affected sons (II-1 and II-2) transmitted the trait to two of their progeny (III-1 and III-4). The sibships were small—three in each family. The ratio was not one to one; nevertheless, it can be said that about one-half of the offspring were affected.

In the third generation, again only those individuals (III-1 and III-4) who were known to have the condition of tibial torsion transmitted the gene to two of their children (IV-1 and IV-8).

Anomalies other than tibial torsion which appear in the third and fourth generations probably bear no relation to the torsion condition. The club feet exhibited in two males (III-8 and III-15) in a sibship in the third generation could, of course, have come from the paternal side of the family. No information was available as to the possibility of this condition coming from the maternal side. Since the inheritance of club feet is being studied as a long-range project in our clinic, we will reserve our discussion of this condition until we have more data. It is unlikely that the club feet in this pedigree have any relation to the gene for torsion.

In the fourth generation, the younger sister (IV-2) of the propositus was born with congenital dysplasia of the hip which corrected itself. Delivery was breech. We believe that this has no relation to the torsion condition. If it were possible for the gene for torsion to exhibit such variability of expression, it is likely that other instances of such deformities would have occurred in this kindred; however, the possibility must not be ignored.

Three individuals out of eight affected have had treatment. The procedure for the propositus (IV-1) has been reported in the foregoing. His mother (III-1) had an osteotomy and re-alignment operation in 1935. Efforts to obtain preoperative roentgenograms have failed, since the roentgenograms made by the attending physician, dating back so many years, have been destroyed. It will be observed that roentgenograms made in May 1956 still show a slight bowing in the left leg (Fig. 2).

The other individual affected with tibial torsion who received treatment was III-4. In this patient, the condition was recognized in infancy and braces were applied. She now walks with a limp. All other affected members of the family show the anomaly to a marked degree. No "spontaneous" correction can be expected;

FIG. 1-C

FIG. 1-D

Figs. 1-C and 1-D: Roentgenograms of propositus, IV-1, made two months after derotation osteotomy.

Fig. 2: Roentgenogram of III-1, made twenty-one years after osteotomy and realignment operation.

this dramatic type of recovery occurs much more frequently in the acquired type of torsion or in instances of bilateral torsion with bow-leg which may have been incorrectly diagnosed and confused with other conditions which result in bowing.

DISCUSSION AND CONCLUSION

Multiple marriages in this pedigree strengthen the evidence of a genetic basis for the inheritance of torsion. The apparent progenitor (I-1) was married twice, transmitting the abnormality to offspring of both marriages. Two later marriages of the mate of II-1 substantiate this conclusion, since none of the progeny of these two unions show the trait.

Examination of Chart I reveals that only those individuals possessing the trait transmit it to their offspring; that the trait manifests itself in every generation; that approximately one-half of the total number of individuals in the family are affected; and that the abnormality affects males and females alike.

A Mendelian autosomal dominant type of inheritance is demonstrated for bilateral medial tibial torsion in this pedigree.

FIG. 2

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An Angled Guide-Wire Director for Use in Treatment of Intertrochanteric Fractures and Fractures of the Neck of the Femur

BY WILLIAM G. DURNIN, M.D., LONG BEACH, CALIFORNIA

Many surgeons who use cannulated metal fixation appliances to maintain reduction in fractures of the neck of the femur or intertrochanteric fractures find the accurate location of the guide wire a tedious and occasionally difficult procedure. To obviate this situation, another somewhat different type of director is recommended. This instrument differs only in detail from those of Engel and May, Moore, Bailey, Hopkins, and others. Its use has greatly simplified the problem of placing guide wires accurately, and it is very easy to apply.

The device consists of a solid steel cone, three and one-fourth inches in length.

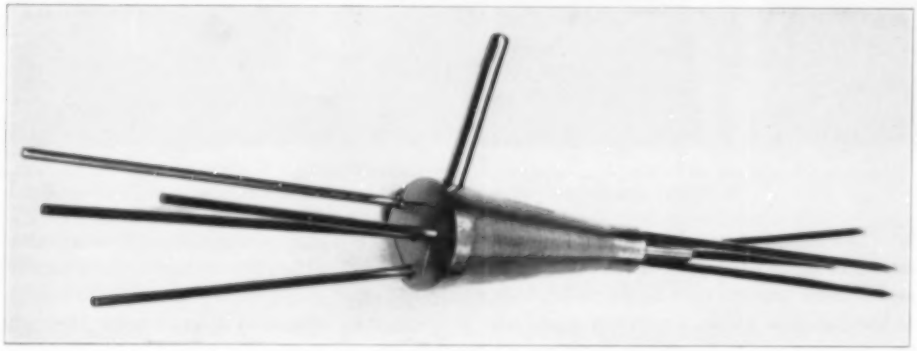

FIG. 1

Through its center from apex to base runs a cannula three thirty-seconds of an inch in diameter. At an angle to the first cannula there is a second, placed at the closest possible approximation to the first cannula at the apex and separated from it one-quarter of an inch at the base. A third cannula placed similarly to the second is three-eighths of an inch eccentric to the first cannula at the base. There is a fourth cannula which is one-half inch eccentric to the first cannula. With this arrangement it is possible to correct a poorly placed guide wire one-fourth, three-eighths, or one-half of an inch in any direction to a depth of three and one-quarter inches, which is the central point in the femoral head in the average individual. Three-quarters of an inch below the apex of the director there is a cuff which is the point of impingement on the lateral femoral cortex when the director is in use. There are directional markers on the base of the cone to correctly position the guide wires.

In using this apparatus, it is first necessary to accurately reduce the fracture by whatever method the surgeon may choose. After adequately exposing the lateral aspect of the proximal portion of the shaft of the femur, a primary guide wire is inserted. The author uses the following technique: an incision is made over the lateral aspect of the thigh over the upper end of the femur*. An opening of one-fourth to three-eighths of an inch in diameter drilled through the lateral femoral cortex at the level of the lesser trochanter is directed at an angle proximally, toward the neck of the femur. Larger openings in the

*The fascia lata and vastus lateralis are split longitudinally and the lateral aspect of the proximal three inches of the shaft is exposed.

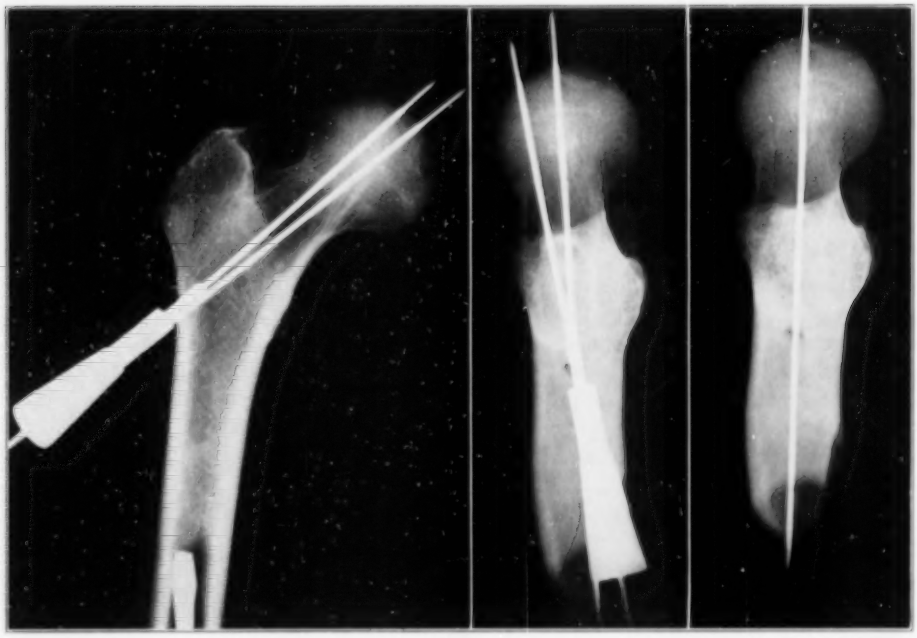

FIG. 2

Roentgenograms show correction obtained by use of the director.

lateral femoral cortex have been made using the same technique. Limited extracapsular dissection about the neck of the femur is carried out in order that the outline of the anterior and inferior aspects may be palpated. Using extracapsular, palpable aspects about the neck of the femur as guide, a primary guide wire is inserted by means of a handchuck through the opening in the lateral femoral cortex up through the medullary cavity of the femoral neck and into the head of the femur. The ideal site of insertion for this guide wire is just posterior and distal to the center of the head of the femur. If this guide wire is found roentgenographically to be in good position, there is no need to use the director, and the permanent fixation device may be applied according to the usual technique. However, accurate placement of the guide wire is not always achieved. When the displacement of the primary guide wire is observed roentgenographically, the direction of the necessary correction is noted. The director is then firmly fixed, apex down, by passing the primary guide wire through the central cannula until the cuff impinges on the lateral femoral cortex. One of the eccentric cannulae is selected and the director is rotated to the desired position as indicated by the directional marker on the base. Another guide wire is then inserted through the appropriate cannula. The second guide wire is drilled into the lateral femoral cortex to the desired depth. A roentgenographic check should show it to be in good position. The primary guide wire and the director are then removed and permanent fixative apparatus is applied.

When the surgeon has acquired dexterity in the use of the director, the roentgenographic check of the second guide wire can frequently be dispensed with.

Occasionally, the correction desired may be as much as three-fourths of an inch or one inch. A larger director may be used or if one is not available, the necessary correction may be made using the director described and a two-step procedure. The foregoing technique is used, and the first one-half inch of the primary guide-wire insertion is corrected. The first guide wire is then withdrawn and the director is removed. The director is applied again, running the second guide wire through the central cannula. A third guide wire is

then inserted through one of the eccentric cannulae into the lateral femoral cortex, to complete the necessary correction. Permanent fixation is then applied.

This device has been used in over fifty patients and it has been used in many laboratory experiments. In every instance, the director, when properly applied, has made the necessary calculated correction. It is simple to operate and it is most accurate. It is of particular value to those who do not often operate on fractures of this type.

To summarize the technique of using the angled guide-wire director:

1. Fit the director over the poorly placed guide wire.
2. Calculate the direction and distance of the amount of correction necessary.
3. Insert a second guide wire through the appropriate cannula.
4. Drill the second guide to the desired depth in the lateral femoral cortex.
5. Check its position roentgenographically.
6. Remove the first guide wire and the director.
7. Apply fixative apparatus.

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Hip-Nail Index

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The need for a rack for holding hip nails is apparent to the operator who, at surgery, requests a certain length nail and must wait while the assisting nurse sorts, measures, and compares the nails which invariably lie loose on the instrument table. The requisites for any such rack are that it be easily cleaned, that it be a sterilizable unit, that it hold the

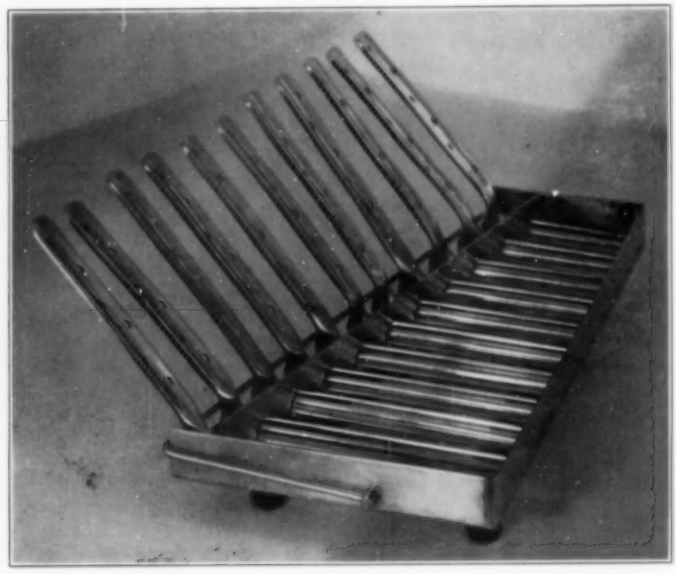

FIG. 1

The hip-nail index illustrated holds eleven nails. The nails are from three to five and one-half inches long.

nails firmly, that the desired nail be readily located and easily removed, and that it be readily apparent if a nail is not in its proper place. A device incorporating these features and capable of holding any triflanged hip nail is presented. A nail which is incorrectly placed in the holder will not permit the fastener to close if the nail is too long; and if it is too short, it will not engage the fixing pin and be obviously loose. The advantages of having the correct length of nail immediately available are many. This device (Fig. 1) has been called a hip-nail index because it not only holds but automatically indexes the nails. It has been of value not only to the operating surgeon but also to the surgical and instrument nurses.

REPORT OF THE VISIT OF THE 1957 AMERICAN AND CANADIAN TRAVELING FELLOWS TO GREAT BRITAIN

By J. William Fielding, M.D., New York, N. Y.

On April 17, 1957, five of us—Robert W. Bailey of Los Angeles, Paul H. Curtiss of Cleveland, J. William Fielding of New York, Edward D. Henderson of Rochester, Minnesota, and Robert N. Lofthouse of Hamilton, Ontario, Canada—were the guests of Dr. Halford Hallock at an informal dinner in New York City.

The following morning we boarded the *United States* bound for England. The crossing was an excellent opportunity to change acquaintances into friends and to prepare for the magnificent tour ahead.

On April 23, five days later, the ship docked at Southampton. Almost immediately we were greeted on board by Mr. Philip Wiles, the President of The British Orthopaedic Association, and by Mr. J. I. P. James, the Secretary. Through some magic compounded by Mr. Wiles, we found ourselves through customs, in a first class railroad carriage having tea, and on the way to London—all in the blink of an eye.

In London, we were taken to the Lansdowne Club, briefed on the activities to follow, and given funds to last us through the remaining six weeks.

Our tour took us to twenty-eight hospitals in seventeen cities. It extended northward from London, up the west side of Britain to Aberdeen, and thereafter southward on the east back to London.

In London, we visited five hospitals. At the first, the Middlesex Hospital, Mr. Wiles pointed out that the British had been greatly disappointed in the results following the overenthusiastic use of the acrylic Judet prosthesis. This has lead to a more conservative means of management of hip problems.

In the operating theater, Mr. Wiles and Mr. Philip Newman performed a Bankart procedure for recurring dislocation of the shoulder, a tibial tubercle transplant, a knee fusion, a lumbosacral fusion, and a McMurray osteotomy.

The welcoming dinner that evening at the Royal College of Surgeons was attended by orthopaedic surgeons whose names are familiar wherever the specialty is practiced. Among them were Mr. Wiles, Mr. H. J. Seddon, and Mr. H. Osmond-Clarke. This dinner, with its peerless British hospitality, was a fitting beginning to our tour.

The Orthopaedic Department of King's College Hospital, our second stop, is under the direction of Mr. H. L.-C. Wood and is justifiably proud of its connection with Lord Lister. Here we saw many of his surgical instruments and read notes in his own handwriting. Among the subjects discussed at this Hospital were pes cavus, the relationship of tumors and infection of the the genito-urinary tract to spinal lesions, and the diabetic foot.

FIG. 1

The third day in London took us to the Royal National Orthopaedic Hospital and Mr. Seddon. Here, Mr. H. Jackson-Burrows and Dr. J. T. Scales reviewed their experience in cases in which massive amounts of bone had been replaced by prosthetic devices. Patients were shown in whom polyethylene prostheses had been used to replace the upper third of the femur to provide an adequate stump for the fitting of an artificial limb in cases of hip disarticulation. Other massive replacements included the upper half of the humerus. In one patient the knee joint (and the adjacent portions of the tibia and femur) had been replaced. When we saw the patient two years and five months after surgery, the knee was functioning well.

These men feel that the devices are best secured to the bone by side plates held by screws rather than by intramedullary means. While the results were encouraging, the technique is still experimental.

At Stanmore that afternoon Mr. Seddon discussed Volkmann's ischaemic contracture. He stated that if the muscles are living and contracted, a muscle slide operation is done. If they are dead, an excision and reconstruction is performed. He then demonstrated the use of the pedicle nerve graft and showed a patient in whom a fourteen-centimeter gap had been bridged. Thereafter Mr. James discussed scoliosis.

On Saturday, April 27, we visited the port of London, the Thames, the Greenwich Observatory, and the Royal Naval College. We were honored to have as guides the Chief Inspector of the Harbor Police and Captain St. John Cronyn, a former Director of the Tactical School at the Royal Naval College.

At our fourth hospital, St. Mary's, Mr. John Crawford Adams provided us with a very stimulating day. Mr. Adams, who himself developed a hip arthroplasty cup, has now discontinued use of hip arthroplasty and feels fusion to be more reliable.

He is in favor of the V arthrodesis in which a nail is placed across the joint and fibular graft is inserted through a prepared hole in the femur into the ischium. It is indicated in stable painful hips with little motion.

FIG. 2

The 1957 American and Canadian Traveling Fellows: (from left to right) Robert W. Bailey, Los Angeles, California; Edward D. Henderson, Rochester, Minnesota; Robert N. Lofthouse, Hamilton, Ontario, Canada; Paul H. Curtiss, Cleveland, Ohio; and J. William Fielding, New York, N. Y.

Mr. Adams performed such an arthrodesis for us with rapidity and ease. He allows his patients to walk within six weeks and feels that solid bone fusion can occur within two months. In fifty cases, he knows of only four which failed to fuse.

Another highlight of our day at St. Mary's was a visit to Sir Alexander Fleming's original laboratory, conducted by Lady Fleming.

Among the cases presented at the clinical session was one in which a fibular head had been used to replace a femoral head which had been destroyed by osteomyelitis. The result from this surgery was not impressive, but the upper part of the fibula, including the epiphysis, grew to an essentially normal appearance. Mr. G. W. L. Bonney then outlined how buttock claudication due to internal iliac artery occlusion could simulate herniated intervertebral disc. When surgery was indicated, thrombo-embolectomy or an arterial graft relieved the symptoms.

Our final day in London was spent with the orthopaedic group at the London Hospital. Its staff includes Sir Reginald Watson-Jones, the director, Mr. H. Osmond-Clarke, Mr. W. A. Law, and Mr. O. Vaughan Jackson. At the morning session the latter showed us how tendons in rheumatoid hands could chafe over an exostosis at the wrist and rupture. He suggested that this be kept in mind when considering disability in these hands.

Mr. Law has done over 100 osteotomies of the spine for rheumatoid spondylitis. He pointed out that the deformity will recur if it has not been completely corrected or slightly overcorrected. This may require

repeated osteotomy at one or two other levels. Mr. Law has done well over 1,000 Smith-Peterson cup arthroplasties of the hip and feels that this procedure when indicated, can offer good results in about 80 per cent of patients. The six representative cases shown were certainly impressive.

May 1 and 2, Alton

From London we journeyed by rail to Winchester where we were treated to a tour of the magnificent 900-year-old cathedral. In Alton, at the Lord Mayor Treloar Hospital, among the cases shown, we saw how mobile claw toes were corrected in a child by means of transplantation of the long toe flexors into the extensors.

May 3 and 4, Cardiff and Chepstow

In South Wales we visited two centers. The first, the Prince of Wales Orthopaedic Hospital in Cardiff, is a converted United States Army Hospital. The staff under Mr. A. O. Parker presented many interesting cases. Mr. E. W. Meurig Williams showed film on paraplegia, a common result of cave-ins in the Welsh coal

FIG. 3

The A. B. C. Club farewell dinner.

mines. He recommends open reduction of the displaced facets and stabilization by plating the spinous processes. Mr. Dillwyn Evans showed us how, by means of a calcaneocuboid fusion combined with a medial release and a lateral transplantation of the tibialis anterior, a resistant club foot could be held from further deformity pending the performance of a triple arthrodesis.

At the second center in this area, St. Lawrence Hospital in Chepstow, Mr. Emlyn Lewis demonstrated his method for determining viability of tissues by the injection of disulphene blue intravenously. Those tissues not taking up the dye were felt to be non-viable. However, the whole body, including the face, turns grass-green. We were told that this disappeared after a few days. The technique was interesting but we felt that it required more investigation before being accepted as a standard procedure.

A scenic automobile trip up the Wye river valley to Stratford followed. Here we attended a performance of *As You Like It* and visited the birthplace of William Shakespeare.

May 6 and 7, Birmingham

At Birmingham, in the heart of the heavily industrialized midlands, we attended conferences at both the Royal Orthopaedic and Accident Hospitals. At the former, Mr. F. G. Allan, the director, discussed limb lengthening, and later presented a patient in whom six inches had been gained. Then Mr. A. M. Hendry pointed out that McMurray's osteotomy is valuable in the treatment of painful osteo-arthritis and other lesions of the hip. Several unselected patients were shown, all of whom had improved.

At the Accident Hospital, under Mr. W. Gissane, a series of fractures of the forearm was presented which suggested that the optimum time for open reduction is from fourteen to twenty-one days after fracture.

May 9, 10, and 11, The British Orthopaedic Association Meeting

Part of this meeting was held at Shrewsbury. The remainder was held at the Robert Jones and Agnes Hunt Orthopaedic Hospital at Oswestry. The excellent papers presented will no doubt appear in the

British Volume of The Journal and will not be summarized here. Two of us (R. W. B. and J. W. F.) participated in the program.

The orthopaedic hospital at Oswestry is not only rich in orthopaedic tradition but is staffed by some of the most competent orthopaedists in Britain. This was borne out by the clinical material exhibited during the course of the meeting. At these exhibits, 200 of the patients concerned were available for examination and questioning.

May 12, 13, and 14, Manchester

Mr. D. Lloyd Griffiths, the orthopaedic director of the Manchester Royal Infirmary met us at Shrewsbury, and with Mr. J. R. Hughes, took us on an automobile tour of North Wales.

Although it rained, the brilliant personality and vivid descriptions of our hosts more than offset the unfavorable weather conditions.

The following day in Manchester, Dr. Stanbury, an internist, discussed renal osteodystrophy which may exist unnoticed in elderly people complaining of vague aches and pains. He suggests treatment with Vitamin D.

Mr. A. C. H. Ratliff had extensively studied leg shortening in poliomyelitis. He believes that there is no constant correlation between paresis and shortening except in the very flail extremity. The maximum shortening is rarely over three inches. These conclusions were based on a series of 192 cases with an average follow-up of eleven years.

At Park Hospital, Davyhulme, Mr. John Charnley with unusual skill and speed performed his central dislocation hip arthrodesis and later conducted a very profitable visit to the wards of his hospital. We were intrigued by the remarkable ingenuity with which he applied the compression principle. One of our number (P. H. C.) remarked that he could not understand how a person with such an expansive personality could be so interested in compression.

May 16, 17, and 18, Glasgow

We traveled north by car through the beautiful Lake District, across the Scottish border into the Lowlands to Glasgow. Here we were privileged to visit three hospitals. At the first of these, Killearn, Mr. Roland Barnes, the director, spoke on tuberculosis of the spine, favoring a direct procedure on the diseased vertebrae rather than a posterior fusion.

At the Royal Hospital for Sick Children that afternoon, Mr. N. J. Blockey told us how, in children under six, the odontoid process does not fracture but tends to separate at the epiphyseal line between it and the body of the second cervical vertebra. He feels these injuries may be overlooked on an anteroposterior roentgenogram because the displacement of the epiphyseal line is usually forward or backward and can only be seen well in the lateral projection. Satisfactory results can be obtained in these injuries if they are recognized and treated early.

Mr. A. G. Quinlan discussed how compression fractures of vertebrae can occur in children with tetanus even without convulsions.

At the Royal Glasgow Infirmary, Mr. A. MacDougall demonstrated how maternal birth palsy can occur by the fetal head compressing the lumbosacral trunk against the pelvic brim.

Philipshill was our third and last stop in Glasgow. There Mr. A. R. Parkes told us how ganglia of the superior tibiofibular joint can infiltrate the peroneal nerve and cause paralysis. His treatment was to ligate the neck of the ganglion.

Close to Glasgow is Loch Lomond, to which we were taken by Mr. A. MacDougall and Mr. A. G. Quinlan. Even through rain and fog, this Loch, famed in song and story, completely lived up to its well deserved reputation for beauty.

May 19, 20, and 21, Aberdeen

From Glasgow our hosts drove us into the Highlands, past moors and lakes, over mountain passes to Nethybridge, the most northerly point of our tour. Here we were met by the group from Aberdeen, two of whom, Mr. G. Hay and Mr. N. G. C. Hendry, appeared in their traditional tartan kilts.

At the Royal Infirmary at Aberdeen we enjoyed a well rounded program under the direction of Mr. A. M. Rennie. Mr. A. Adam discussed McMurray's osteotomy for osteo-arthritis of the hip based on a series of fifty-eight cases. The indication for the procedure is pain. On this basis 66 per cent of the results were considered good, 20 per cent fair, and 14 per cent poor. In the roentgenograms of five of the cases we were surprised to see that the joint space appeared to have become wider.

While in Scotland we enjoyed a visit to "Cragievar" the ancestral home of Lord Sempill, of the clan Forbes. Wearing a family tartan kilt, he greeted us in Gaelic, and proudly took us on a tour of his beautiful home, during which he vividly described the legends and heritage of his clan.

May 22, and 23, Edinburgh

It was a great pleasure to visit this old and famous city, with its castle and Firth of Forth bridge. It was an equal pleasure to meet a person as modest and yet as capable as Sir Walter Mercer. At the Royal

Infirmary we saw him perform a Brittain shoulder fusion. Later Mr. D. L. Saville presented an ingenious method of repairing old and recent ruptures of the tendo achillis using strips of tendon from the gastrocnemius. The results were excellent.

At the Princess Margaret Rose Hospital, Mr. R. I. Stirling, the director, ably assisted by Mr. G. P. Mitchell, had prepared an excellent program. Mr. W. V. Anderson presented the results of 140 leg lengthenings done over twenty-four years in which up to three and one-half inches in length was obtained with few complications. He feels that the prime indication is considerable paralysis in the leg to be lengthened. He is reluctant to lengthen an otherwise normal leg. Osteotomizing the fibula and transplanting it to the tibia prevent valgus deformity occurring in the foot as the leg is lengthened.

The use of arthograms to outline the limbus in congenital dislocation of the hip was discussed by Mr. Mitchell. It is resected if it prevents socketing of the head of the femur.

May 24, 25, and 26, Newcastle

We were met at the station by Mr. G. Irwin, the Orthopaedic director of the Royal Victoria Infirmary. Mr. P. Robson, the senior registrar, discussed hyperextension injuries of the cervical spine with paralysis. He felt that this was due to pressure on the cord from bunched up ligamentum flavum aggravated by backward pressure from exostosis in the intervertebral regions.

Mr. Irwin, mindful of the points of interest in his area, arranged visits to the cathedral at Durham, completed in the early Twelfth Century, and to the Roman Wall. The visit to the Wall was fascinating and could not have been better planned. We were privileged to have as our guide Mr. J. P. Gillan, the Professor of Roman British Archeology at Newcastle University. We were fascinated by his extensive knowledge of the subject. His descriptions of the forts, the legions, and the life in Roman Britain were vivid and dynamic.

May 27, Leeds

At the General Infirmary, Mr. A. B. Pain surgically demonstrated the Crockatt osteotomy for metatarsus varus. It consists of a wedge osteotomy at the base of the first metatarsal, and a simple osteotomy through the base of the second and third metatarsals. Mr. J. M. P. Clark, the energetic director at Pinderfields, in two hours, presented 120 cases in which tendon transfers had been done in various parts of the body, largely for poliomyelitic paralysis. We cannot help but remember his indications for these procedures. Mr. Clark believes that in the foot tendon transfers should be done for balance, pending stabilizing bonework. The tendon transferred need not be of normal length. In the upper extremity only normal or near normal muscles should be used.

May 28, Sheffield

The program here under Mr. F. W. Holdsworth and Mr. A. Hardy, was devoted to paraplegia. Lodge Moor Hospital is concerned entirely with this problem and its many ramifications. Here the patient can be managed intensively and intelligently from injury to final disposition. Mr. Hardy feels that laminectomy is seldom, if ever, indicated and that, if after eight hours, there is no return of sensation or voluntary power, the cord has been badly damaged and the prognosis grave. Similarly grave is the early development of signs of upper motor neuron lesion. He discussed the varieties of lesions that could occur and described how the cord at a given level could be injured and the roots passing at the same level be uninjured, so-called "root sparing."

May 29, Derby

Here Mr. R. G. Pulvertaft of the Royal Infirmary exhibited exceptional skill in performing a flexor-tendon graft in the hand. Later Mr. Adkins discussed the preliminary results of his primary bilateral intertransverse process fusion for lumbosacral arthrodesis. He voiced dissatisfaction at the results of his previous attempts to fuse this interval using the posterior and interbody methods. Although the roentgenograms of the cases presented showed very good fusions, we felt that posterior arthrodesis might give better support.

May 30 and 31, Cambridge

Our visit to this old and hallowed university town came near the end of the tour, and The British Orthopaedic Association kindly arranged half-day sessions. The remainder of the time we profitably spent investigating the halls of learning, punting on th. .iver Cam, and exploring the town itself.

Among the many stimulating and scholarly presentations at Addenbrooks Hospital was one by Mr. R. W. Butler, the director. He described how in vertebral osteochondritis, the intervertebral-disc structure breaks through the cartilage plate and strips off the epiphysis from the vertebral body anteriorly. This leads to a loss of growth in the anterior part and the characteristic round-back deformity. He suggests conservatism in therapy.

June 1 and 2, London

During our final visit to London we were entertained in the relaxed atmosphere of the homes of Mr.

Philip Wiles and Sir Reginald Watson-Jones. The farewell dinner was under the genial chairmanship of Mr. H. Osmond-Clarke. All but two of the British members of the A. B. C. Club were present, some of whom had come all the way from Scotland to attend.

June 4, Luton

Our final day was at the Vauxhall Motors rehabilitation center under the able direction of Mr. L. W. Plewes. Here we were introduced to the "third" phase of medicine, "rehabilitation" which, at this center is not a specialty unto itself, but a very integral part of orthopaedic surgery. It was impressive to see how an informed labor-management group cooperates fully with the physician-engineer combination in effecting early return of patients to gainful and productive effort.

CONCLUSIONS

Needless to say it is impossible to reduce such a magnificent experience to a few printed pages. Space does not permit other than a brief summary of the events and places visited.

In Britain we found the orthopaedic problems were essentially the same as in America. While the approach to these problems may at times differ from ours, the results, in some seem to be better, while in others they were perhaps not as satisfactory.

Tuberculosis is somewhat more prevalent, but as in the United States and Canada, a definite decline in frequency is noted. There is a great tendency to drain abscesses and remove necrotic débris with antibiotic treatment. In spinal lesions this is done by a costotransversectomy, or by an anterolateral approach. The patient is kept recumbent until stability occurs anteriorly. Posterior fusion is advocated only when the spine is markedly unstable. However, we feel that primary posterior fusions can and do give good results.

Joint tuberculosis, if seen early, is treated conservatively with antibiotics in an attempt to preserve function. If the joint has been destroyed, a fusion is done. This is a concept which is held by many on both sides of the Atlantic.

The acrylic Judet prosthesis, at one time widely accepted, has proved to be unsatisfactory in Britain. We saw few prostheses of any type, probably due to the bitter experience with the Judet. Cups too were generally believed to be unsatisfactory. The British, in search of a means of solving the problem, have resorted to fusions, Girdlestone operations, and the McMurray osteotomy. The results of the latter procedure were some of the most impressive seen on the tour. The procedure is only done for the relief of pain, and for the most part in osteo-arthritis of the hip. There is no unanimity of opinion as to why it is successful. It would appear that the only common denominator is division of the femur. Some have used internal fixation, and some not. Unlike the patients treated with the insertion of a prosthesis, these patients improve with time. Long-term unselected follow-ups were shown in more than one institution. In some instances the joint space, on the roentgenograms, appeared to re-form.

When we were first presented with the McMurray osteotomy we were skeptical as to its value. As time went on we were able to question and examine more patients on whom this had been done. We then became more impressed with its place as a pain relieving procedure.

Traumatic paraplegia is treated by open reduction of the dislocated facets to relieve any cord pressure, and by plate stabilization. This allows early mobilization and is followed directly by early and constant physical therapy. Spine fusion is rarely done at the time of open reduction. The experience of both Mr. Meurig Williams at Cardiff and the group at Lodge Moor Paraplegic Center is that in the majority of instances spontaneous interbody fusion will occur. The results, in spite of adequate care, are generally poor. Laminectomy is felt to be rarely, if ever, indicated.

Congenital dislocation of the hip, if seen before the child is eighteen months old, is managed by abduction. In older children open procedures are generally resorted to. Arthrograms are popular to determine the position of the limbus, which is resected if it blocks reduction. Derotational osteotomy is frequently used.

Joint arthrodeses are performed by a variety of techniques with the exception of knee fusions which are almost invariably done by means of compression.

In Britain, tendon transfers seemed popular. In the foot they are used to prevent deformity pending bone stabilization if such proves necessary. Weakened muscles are sometimes transferred. In the upper extremity it is felt better to use normal muscles for the purpose. In some instances it appeared that a primary bone stabilization might have given a more satisfactory result.

Leg lengthening procedures were shown to us in more than one hospital. Considerable length was gained but in some patients there were complications.

We saw numerous operations aimed at correcting foot deformities. One of these, the Dwyer procedure, is for correction of varus or valgus heel. It consists of an osteotomy through the calcaneus. Several good results of this procedure were shown. Relapsing club feet, refractory to plaster-cast correction, were managed by a medial release and tendon transplants, usually tibialis posterior through the interosseous membrane, or a lateral transplant of the tibialis anterior. Mr. Dilwyn Evans of Cardiff combines this with a calcaneocuboid fusion.

The problem of mobile claw toes in children was managed in some centers by a transfer of the long flexors to the dorsal extensor expansions. The results were impressive.

We were introduced to a procedure known as the "ten-toe-ectomy" designed for painful and uncorrectable claw toes. As the name implies it consists of amputation of all ten toes. The shoes are fitted with an insert postoperatively to take the place of the amputated digits. It appeared to be a rather radical way to handle this problem, but the patients we saw on whom it was done were satisfied.

Hallux valgus is treated by a Kellar procedure or by fusion of the metacarpophalangeal joint using catgut sutures for fixation or a screw across the joint.

In conclusion, we extend our most sincere thanks to The American Orthopaedic Association and The Canadian Orthopaedic Association for sending us. Selection as a traveling fellow imposes an honor, and a responsibility that we cannot adequately define. The memories of the trip will always be with us. New British acquaintances have quickly become old friends. With the passage of time the value of this period of study will be of even greater importance to each of us.

Our British hosts were magnificent, and could have given no more cordial reception, nor could they have shown greater hospitality. To each of them we express our deepest thanks.

The program as presented could not have been improved upon. The careful planning, the many centers visited, allowed us to see a cross section of orthopaedic surgery in Britain. Two men were extremely helpful, Mr. Philip Wiles, the President of The British Orthopaedic Association, and Mr. J. I. P. James, the Secretary, who worked together to organize a magnificent itinerary.

We sincerely hope that the Traveling Fellowship continues, and we shall do our utmost to propagate the information gathered in Britain.

Proceedings

FIFTIETH ANNIVERSARY

HOSPITAL FOR JOINT DISEASES

An Alumni Scientific Meeting was held at the Hospital, November 15 to 17, 1956, commemorating the Fiftieth Anniversary of the Hospital.

The following scientific program was presented:

Factors Responsible for Stability of the Knee Joint. Dr. Emanuel B. Kaplan discussed other factors, in addition to the lateral and medial collateral ligaments, which are of importance: the iliotibial band and popliteus muscle and tendon for the lateral region of the knee, the semimembranosus muscle and tendon for the medial aspect of the knee, and the patellar retinacula in front of the knee. The study was based on experiences in surgery of the knee following trauma, electric stimulation of muscles exposed by surgery, comparative anatomy of the knee, and anatomical dissection of human knees.

Use of Risser Ambulatory Jacket in Scoliosis. Dr. Jacob J. Graham described his experiences with the use of the Risser ambulatory localizer cast in the treatment of scoliosis. He pointed out that this method merely represents a refinement of a technique which employs three fundamental principles in the treatment of scoliosis: counteraction of the force of gravity, longitudinal traction as a corrective force, and pressure over the convexity of the curve.

Supposed Predislocation of Congenital Dislocation of the Hips: Clinical and Radiographic Features. Dr. John Caffey [1] emphasized that the current preventive practices for congenital dislocation of the hip, the use of the Frejka pillow splint, and the Hass bar, are based on the hypothesis that the predislocation phase can be identified roentgenographically by high acetabular angles in combination with limitation of abduction and external rotation. Records of the size of the acetabular angles, measured roentgenographically in 1,500 unselected newborn infants, were presented with follow-up roentgenographic measurements at six months and twelve months of age. Dr. Caffey stated that these findings indicate a wide variation in the size of the acetabular angles in healthy infants; approximately 50 per cent of white female infants have angles greater than 29 degrees, which has been widely used as the upper limit of normal. He said that the findings in this group, by far the largest unselected infant population measured for size of the acetabular angles, demonstrate that the predislocation phase of congenital dislocation of the hip is

[1] Professor of Radiology, Columbia University College of Physicians and Surgeons, New York, N. Y.

being diagnosed too frequently and that unnecessary preventive measures are being applied to large numbers of healthy infants.

Experience with a Conservative Program in Treatment of Congenital Dislocation of Hips in Infancy. Dr. Joseph E. Milgram reviewed a series of cases of infants and children which convinced him that manual replacement is fraught with danger of capital necrosis. Furthermore, selection of cases and methods of reduction based on experience with older patients are not applicable to young patients and may lead to capital femoral injury. Dr. Milgram pointed out that the youngest patients are most vulnerable to capital necrosis and that severe femoral head changes may follow the "gentlest manual reduction" without anaesthesia. Moreover, in early infancy even gradual reduction by abduction may not be without complications in certain cases, although it is usually without peril in cases properly selected. It was pointed out that under special circumstances the normal hip may also undergo cystic alterations on abduction; in other cases reduction by traction methods is safest. Spontaneous reduction is sought whenever possible during the course of traction. He said that Hoke's traction cast applied to the unaffected limb has, since 1927, proved to be a practical method for traction reduction in the home or hospital. Dr. Milgram stated that maintenance of reduction in the young is seldom a problem and a frog-position spica is efficient except with ligamentous relaxation and that excessive capsular relaxation and excessive instability are best controlled by fixing the limb of the reduced hip in internal rotation. While primary internal-rotation fixation has in some young patients been blamed for capital vascular changes even on the normal side, it was harmless in the presence of ligamentous elongation. He reported that anteversion rarely constitutes a difficulty in maintaining the position except in patients with ligamentous relaxation; operative correction is rarely required in infancy and the deformity spontaneously diminishes after reduction. It was pointed out that it is possible to select cases applicable for treatment by abduction and those best treated by traction by comparing roentgenograms in the neutral and abduction positions. Dr. Milgram said that if the head of the femur points toward the acetabulum, gentle increasing abduction with flexed knees (never straight-knee casts) will usually result in spontaneous reduction. If the femoral head points toward the secondary acetabulum or rides upward, traction to pull the head down is essential for spontaneous or relatively atraumatic reductions on subsequent abduction. An analysis was presented of 124 dislocations based on the prognostic value of prereduction roentgenograms. Correlations were demonstrated between the roentgenographic findings and the changes in the capital femoral epiphyses which followed various programs of treatment. The safety of traction programs was apparent in appropriately selected cases. It was emphasized that repair and reconstruction of the impaired femoral head occur slowly and spontaneously, and that roundness of the head and acetabular development appear to be facilitated by flexion and rotation performed in abduction splints. To ensure the deepest possible socket, weight-bearing on the re-forming head is not permitted. Thigh abduction splints with the knees free may be desirable for several years.

Dissociation of Metabolic and Growth Activities in Cartilage and Bone. Dr. Richard H. Follis[2] stated that while most of the adult skeleton is preceded by cartilaginous structures which resemble

TABLE I

Disease	Chondroblast	Osteoblast
Cytochrome oxidase	O	+
Osteogenesis imperfecta	N	D
Scurvy	N	O
Copper deficiency	N	D
Dyschondroplasia group	D	N
Vitamin A deficiency	D	N
Congenital syphilis	N	D
"Lattice" formation	N	D
Transverse line formation	D	N
Hypervitaminosis D	D	I

N-Normal D-Decrease I-Increase O-Absent

in miniature the final form of the bone, a close relationship of cartilage to bone during the growth period has led many to assume that the biochemical and formative activities of the chondroblast and osteoblast are rather similar. He said that sometimes this is not so; the cartilage and the bone cell may behave quite differently. Growth of cartilage may be normal when that of bone is impaired; conversely, chondroblastic

[2] Chief, Nutritional Diseases, Armed Forces Institute of Pathology, Washington, D. C.

activity may be depressed when the bone cell is functioning normally. Some disease states which exemplify this dissociation of the activities in cartilage and bone were presented in Table I.

Management of Osteomalacia and Osteoporosis. Dr. Calvin H. Plimpton [3] reported that in osteomalacia the serum calcium and phosphorus are usually inadequate and that osteoid appears in relatively large proportions. In osteoporosis there is no mineral abnormality in the serum and the trabeculae appear normally calcified but unusually thin. He said that this distinction has been useful, but seems an oversimplification; there are many areas of overlap. By considering the pure effects of such major influences as calcium, phosphorus, Vitamin D, the parathyroid glands, protein, stress, and circulation, a better understanding of the total picture in man may be gained.

Dr. Plimpton stated that while rickets is now very rare in the United States, sprue or other varieties of malabsorption are not uncommon. In this disease the osteomalacia is usually of secondary importance and responds to diet and vitamins. In those cases which require cortisone, calcium and phosphorus balances are also improved. He said that more serious is osteomalacia associated with kidney disease, such as renal tubular acidosis or Fanconi's syndrome, where calcium is used as a source of fixed base. Skeletal pain may be incapacitating and pseudo-fractures may occur. Fortunately this condition can be controlled through another source of fixed base, such as sodium bicarbonate.

It was pointed out that osteoporosis is the most common disease of bone, and is almost universal in older people. The extent of the disease as seen in the roentgenogram does not at all correlate with the patient's symptoms. Although Cushing's disease, cortisone administration and immobilization may account for a small percentage of cases of osteoporosis, its incidence usually is not associated with any disease. It occurs most commonly in women in their fifties as postmenopausal osteoporosis or from sixty onwards as senile osteoporosis. Dr. Plimpton felt that although estrogens and androgens have a favorable effect in animals, many women find that the slight improvement in morale and the occasional lessening of pain which permits more activity is qualified by the unpleasantness of the re-awakened functions of the bosom and uterus. He said that the compression fractures in osteoporosis usually involve the body of the vertebra so that braces can be discarded as soon as pain is relieved. This permits the increased stress which is such an important stimulus to osteoblastic activity.

Urinary Excretion of Amino Acids as Possible Indicators of Metabolic Bone Disorders. Dr. Jacob Kream, Dr. Joseph E. Milgram, and Dr. Frances Edel presented and discussed preliminary results of a controlled study of the urinary excretion of amino acids in normal individuals and in persons with bone disease. The techniques of ion-exchange chromatography and two-dimensional paper partition chromatography were utilized in the study. They felt that much remains to be done before definite conclusions can be reached, but that the implications are inviting.

The Diagnosis and Treatment of Gouty Arthritis. Dr. John H. Talbott [4] presented the generally accepted etiology of gout and emphasized recent investigations aiding the understanding of the disturbance of the intermediary metabolism of uric acid. Ancillary phases of diagnosis were discussed as well as the orthodox features including magnified roentgenography. Methods of prophylaxis during periods between attacks were presented with particular emphasis upon the use of uricosuric agents. The surgical management of chronic deforming tophaceous gout was discussed.

Lesions of Accessory Neurenteric Canals. Dr. Edward B. D. Neuhauser [5] described the neurenteric canal of Kovalevsky as a normal but evanescent structure occurring during early embryological life in association with the distal portion of the notochord. Remnants of this canal may persist. Similar, but evidently accessory, canals may form and the unobliterated remnants may give rise to anomalies of clinical significance. The cases of four patients with a neurenteric cyst were presented in detail as examples of such a malformation. Roentgenographically this lesion is characterized by a defect in the anterior aspect of the spine with faulty formation of the vertebrae and a mediastinal soft-tissue mass. The mass may be continuous with a giant diverticulum or duplication of the intestinal tract and associated with a diaphragmatic hernia. It was suggested that diastematomyelia, mid-line dermoids, and other anomalies represent different manifestations of this developmental aberration.

The Surgical Treatment of Malignant Tumors of Pelvis and Hip. Dr. C. Howard Hatcher [6] reviewed some experiences with primary neoplasms about the hip and pelvis, particularly those treated with wide regional resection and located where the major vessels and nerves could be preserved. Methods of reconstruction to regain stability and function were discussed.

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[5] Radiologist-in-Chief, Children's Medical Center, Boston, Massachusetts.
[6] Professor of Orthopaedics, University of Chicago, Chicago, Illinois.

It was admitted that results of therapy of the usual osteosarcomata and fibrosarcomata and undifferentiated round-cell tumors are discouraging. Malignant tumors about the hip and the pelvis from their inception seem to have a greater probability of fatal outcome than do tumors elsewhere. Dr. Hatcher said that the rich vascularity of the pelvic region, affording easy access of tumors into the veins, undoubtedly is a factor in their early spread. Difficulty of adequate surgical eradication of such neoplasms also unfavorably influences the survival rate of patients with tumors in this area. It was pointed out that many surgeons are reluctant to perform interilio-abdominal amputation for neoplasms with so small a possibility of cure and in consideration of the severe functional and cosmetic disability entailed. Consequently, some patients are inadequately treated or receive no treatment at all.

Dr. Hatcher said that the innominate bone and the proximal portion of the femur are areas favored by cartilaginous tumors. It was emphasized that these neoplasms vary greatly in their malignant tendency, ranging from a very slowly growing, late metastasizing neoplasm to the most highly malignant of tumors. It is, he said, with these more slowly growing cartilaginous neoplasms that early surgical eradication gives the most gratifying results, for many of them can be removed without serious sacrifice of function. Unfortunately, there still exists a tendency to underestimate the seriousness of such cartilaginous tumors and to apply inadequate initial surgery. Although these tumors may not metastasize, it was pointed out that they do disable and eventually kill the patient by local extension of tumor. Partial removal or curretage of such neoplasms serves only to seed the tumor throughout the wound and makes more difficult its future surgical removal. Likewise, the employment of irradiation to such tumors fails not only to eradicate them but also makes subsequent surgery more hazardous.

Dr. Hatcher emphasized that tumors of innominate bones and the proximal portion of femora must be treated with the same energetic surgery as is applied to the same disorders located in the extremities. Ablation of the neoplasm may at times necessitate removal of the entire hindquarter. In conclusion, it was pointed out that in many instances, regional resection will accomplish adequate removal of the tumor and that surgical repair of the region can restore reasonable stability and function.

Surgical Excision of Metastases to the Lung, Osteogenic Sarcomata, Soft-part Sarcomata. Dr. William G. Cahan reviewed the literature, totalling 300 cases, and included in his report twenty osteogenic sarcomata, five chondrosarcomata and fifty-five soft-parts sarcomata.

Present Status of Fixed Paralytic Pelvic Obliquity. Dr. Leo Mayer stated that the concepts of fixed paralytic obliquity have not been altered during the past five years. He pointed out that as originally described, this condition is a form of paralytic contracture corresponding accurately to other well known paralytic contractures such as fixed talipes equinus, and in the case of the pelvis is more complicated due to the numerous muscles which are involved. There are two main types: that due to abnormalities of the muscles running from the pelvis to the femur, and that due to abnormalities of the trunk muscles. Dr. Mayer said that of these, the anterolateral abdominal muscles and the quadratus lumborum are the most important.

The main advance which he emphasized is an improved operative technique to deal with abnormalities of the trunk muscles. Hitherto the operative procedure consisted in a free transplantation of a strip of fascia lata. Axer and Clark have improved this technique by leaving the fascia attached to the tensor fasciae latae muscle. The fascia and muscle are freed up to the point where the nerve enters the deep surface of the muscle. The fascia is then brought upward through a subcutaneous channel and fastened to the ninth rib. In this way, it was pointed out, an active muscle is added to the corrective force of the transplant. Three illustrative case histories were presented.

The Dominant Inheritance of Alkaptonuria. Dr. Robert A. Milch described alkaptonuria as an "inborn error of metabolism" characterized biochemically by the inability of the human organism to disrupt the benzene ring of homogentisic (2,5-dihydroxy-phenyl-acetic) acid and clinically by three distinct phases temporally related as a definite syndrome. He said that since Garrod investigated the patterns of inheritance, it has generally been thought that the syndrome is determined by a rare, single, autosomal, completely recessive gene. Direct transmission of the disorder from parent to offspring would then be extremely improbable, even despite consanguineous marriages. He stated that there are, however, a number of reported pedigrees in which precisely this phenomenon has occurred.

Reports of three families with a pattern of direct inheritance were presented. Dr. Milch said that the first case was originally reported by Marshall (1887), later by Futcher (1898) and most completely by Sir William Osler (1904). The second pedigree was presented in part by Pomeranz, Friedman and Tunick (1941), Smith (1942) and White, Parker and Block (1949). The third was previously reported by Dr. Milch (1951, 1955, 1956).

He said that in follow-up studies of each of the families there was evidence of direct transmission of alkaptonuria from parent to child and, at the same time, of failure of its appearance within pedigree lines for extended periods of time. It was pointed out that all studies of the families tended to indicate that the genetics of alkaptonuria may be better explained on the assumption that the metabolic disorder is determined

not by a recessive gene substitution, but rather, by an incompletely penetrant dominant gene substitution, which co-exists with at least one other pair of modifying gene factors. He stated that this would explain the already noted striking excess of consanguineous marriages among parents of persons suffering from the affliction and would adequately account for recorded instances of a seemingly incongruous dominant type of inheritance.

Hyperparathyroidism Originally Diagnosed as Benign Giant-Cell Tumor. Dr. Frederick M. Marek presented the case of a woman, aged forty-six years, with an apparently solitary, large expansile lesion of the shaft of the femur, without any associated systemic abnormalities. A malignant lesion was suspected and a local biopsy was done. The tumor resembled a giant-cell tumor grossly and was diagnosed after frozen and permanent sectioning as a solitary, benign giant-cell tumor. The tumor was completely excised and the surgical defect filled with bank-bone grafts. It was judged not feasible to apply prophylactic internal fixation; external fixation in a plaster-of-Paris spica was used. Four days after the initial operation the patient sustained a pathological fracture through the lower end of the original lesion. Healing of this fracture, filling in of the surgical defect, and amalgamation of the bone grafts seemed delayed. A re-study of the original slides three months after the biopsy established the correct diagnosis of hyperparathyroidism. This was verified by the finding of typical blood chemistry and the parathyroid tumor was subsequently removed. The patient had an uneventful recovery, except for the mechanical defect due to slight angulation and shortening of the femur.

The absence of symptoms of hyperparathyroidism was discussed, the value of routine blood chemistry studies was emphasized, and the differences in the pathology of benign giant-cell tumor and the lesions of hyperparathyroidism were illustrated.

Shoulder-Hand Syndrome. Dr. Otto Steinbrocker discussed the etiology of the shoulder-hand syndrome. An analysis of the clinically determinable causation in over 170 cases formed the basis of the discussion. The possible neural mechanisms underlying the symptoms were outlined. Dr. Steinbrocker's experimental production of reflex dystrophy in animals was reported and the problems raised by these investigations were considered.

History of Osteomyelitis. Dr. Joseph Buchman explained that at the turn of the century a great deal was already known of the pathology, clinical course, and consequences of this disease. Much of the bacteriological aspects was understood while the science of roentgenography was just making its appearance. He pointed out that the necessity for prompt surgical intervention in the acute state was then thoroughly appreciated and practiced and that local chemotherapy was at its height; specific systemic therapy was completely unknown.

Dr. Buchman stated that the great advances made subsequent to the turn of the century were chiefly in the fields of bacteriology and therapy. The appreciation of the mechanics of the bacterial invasion, the roles of the invasiveness and toxigenicity of the bacteria and means of control of these factors led to the introduction of the various serotherapeutic measures which aided greatly in the care of the lesion. He said that the development of systemic chemotherapy and finally of antibiotic therapy is the culmination of recent advances. The limitations of these agents as indicated in recent literature were shown.

Concerning the therapy of the chronic lesion, the survey revealed the gradual progress from haphazard methods during the days before World War I to present-day practices of primary closure under antibiotics.

Special Techniques of Value in Bone Roentgenography. Dr. Maurice M. Pomeranz explained that while standard roentgenographic techniques usually meet the requirements of a busy laboratory, they frequently fall short of the ideal and are of no help in diagnosis. He said that experience has emphasized the necessity for improvisation and the employment of unorthodox techniques where indicated to supplement routine procedures. Among the devices discussed were underexposed and overexposed views, tangential projections, stress films and tomographic films. Stereoscopic films and the utilization of opaque media, considered standard techniques, were not discussed. Examples of the devices were illustrated by lantern slides.

Comminuted Fractures of the Acetabulum with Central Dislocation of the Head of the Femur. Dr. Arthur Holstein presented a modification of the turnbuckle method of treatment devised by Jahss which depends on gradual leverage to produce the desired reduction. The modification was designed to meet the limitations of the Jahss procedure. He said that the materials needed are always readily available, the disturbance to the patient is minimal, the reduction obtained is rapid, there is no need for anaesthesia, and the patient need not be moved from his bed. In his series of cases, there were other patients whose care was not compromised or rendered any more difficult.

Resection Angulation of the Femur for the Redemption of the Hip. Dr. Henry Milch in discussing his operation as a salvage procedure following failure with a hip prosthesis said that the method relieves pain, restores mobility, and re-establishes stability. Resection of the head and neck of the femur

restores the possibility of motion while at the same time it minimizes the pain. Angulation of the femur re-establishes the stability of the hip. He said that it is a procedure applicable to all abnormal conditions of the hip joint. He pointed out that the method was used in the treatment of specific and non-specific inflammations of the hip joint as well as in conditions where stability was lost as in congenital dislocations of the hip, ununited fractures of the hip joint, and unsuccessful prosthetic operations. He stated that it is the best operation thus far devised for all conditions of the hip joint and is the only one which is applicable to bilateral hip conditions. It was reported that in a series of sixty-four operations performed on fifty-six patients it resulted in relief or control of pain in over 95 per cent, with improvement of motion in over 85 per cent.

Reconstruction of Charcot's Knee. Dr. Michael S. Burman pointed out that Charcot's joint is characterized by the destruction of the medial tibial condyle but only limited change on the convex medial femoral condyle. He said that reconstruction of Charcot's joint should break up the vicious circle of destruction and deformity and should protect the region of reconstruction against shearing. He presented his experiences in attempting to meet these demands surgically by reconstruction operations.

Ankle Injuries in Children: Ligament and Epiphyseal. Dr. Barnard Kleiger stated that there are significant differences between ankle injuries in children and those in adults.

One of these differences is in the diagnosis of inversion instability. He said that, according to Bonnin, in adults about 4 to 5 per cent of normal ankles show inversion talar tilt in stress roentgenograms. Therefore, in children, the diagnosis cannot be made on the basis of a tilt alone. He pointed out that if the diagnosis is in doubt, it is better to immobilize the ankle in plaster rather than to risk a permanent instability.

Dr. Kleiger explained that the second difference is the danger of growth interference due to epiphyseal injury; the age of the patient is a determinant of the prognosis. Younger patients with greater growth potential in the uninjured portion of the epiphysis develop greater deformities than older patients.

He further stated that epiphyseal injury may also occur in the course of medical treatment. Roentgen rays applied in the vicinity of an epiphysis may cause serious damage. Partial circulatory obstruction during the course of treatment of fractures or other injuries may also damage an epiphysis. Forceful manipulations to correct existing deformities may cause compression injuries of an epiphysis, and surgical removal of the proximal end of the fibula for use as a transplant will displace the remaining fibula, causing ankle deformity.

Mortality Statistics on Fractured Hips (1935-1955). Dr. Robert Weeden, Dr. Herbert Rosenthal, and Dr. Paul Miller presented a review of all the fractured hips treated at the Hospital for Joint Diseases from 1935 to 1955. Each five-year group was analyzed to demonstrate the influences of age, type of fracture, and method of treatment on the mortality. The cases were studied to determine the specific factors contributing to certain causes of deaths.

There were 938 patients treated, of whom 728 were women and 210 were men. There were 577 femoral neck fractures and 361 intertrochanteric fractures. The authors pointed out that although 10.5 per cent of the patients died in the hospital, mortality decreased over the period of study from 12 per cent to 9 per cent. Their studies revealed a higher mortality in the intertrochanteric cases because the patients were older. The decline in mortality was directly related to the decrease in intertrochanteric fracture mortality through better general medical care.

In analyzing the methods of treatment (spica, traction, and operation), it was observed that, formerly, the majority of patients were treated by spica immobilization. Operative treatment became increasingly predominant and later in the series there was noted a reversal in the choice of management. The proportion of cases treated by traction remained constant. By correlating mortality with treatment the authors found a 6 per cent mortality in 160 spica cases, 9 per cent in 601 operative cases, and 20 per cent in 164 traction cases. They said that the spica method had the lowest mortality probably because the mean age of the group thus treated was from five to ten years younger than the mean age in the other groups. It was concluded that there was lower mortality among patients over eighty when operative methods were used.

They reported that 30 per cent of the deaths were due to pulmonary infarctions, 25 per cent to cardiac causes, 20 per cent to pneumonia, and the remaining 25 per cent to cerebral vascular accidents, uraemia, septicaemia, and other conditions, in that order of incidence. Fifty per cent of the twenty postmortem examinations done in the series showed that death was due to pulmonary emboli and 25 per cent showed that it was due to pneumonia. Although it was felt that pulmonary infarctions were the leading killers in the series, it was pointed out that there were no constant pre-existing factors, or factors in treatment contributory to these embolic phenomena.

Chronaxie Determination in Low Back Lesions. Dr. Irving Mauer discussed his chronaxie studies performed on the lower extremity muscles of 100 patients who were admitted to the hospital with complaints of back ache with or without sciatica. These findings were correlated with clinical and operative findings. He said that preliminary studies were confirmatory that chronaxie determinations are of value in recognizing and differentiating early nerve-root damage possibly secondary to disc herniation and that they are of prognostic value for continued nerve-root pressure.

AMERICAN ACADEMY FOR CEREBRAL PALSY

As prepared by the Publications Committee of the American Academy for Cerebral Palsy

The Annual Meeting of the American Academy for Cerebral Palsy was held in Chicago, Illinois, on November 17, 18, and 19, 1956. Abstracts of the papers presented follow:

Saturday, November 17, 1956

Chemopallidectomy in Involuntary Movement Disorders. Dr. Irving S. Cooper [1] stated that direct attack on the globus pallidus was accomplished by the injection of alcohol under roentgenographic control. Thirty children with cerebral palsy have been so treated, and in twenty of these the tremor and athetosis were abolished. Eight children were not helped, one suffered hemiplegia as a consequence of the operation, and one died. Improvement in those helped was progressive for some months after operation. Greatest application of the treatment was in the severe athetoids with rigidity.

A Rating Scale for the Evaluation of Language Development in the Pre-school Cerebral Palsied Child. Dr. M. D'Asaro, Dr. Irvin Lehrhoff, Dr. I. L. Simmerman, and Dr. Margaret H. Jones [2] presented a scale of language development comprising receptive, phonetic, and expressive elements. The use of these three elements allows for better evaluation of the handicapped child's mental level.

The Presidential Address. Dr. Margaret H. Jones [2].

Ways in Which Physicians Influence the Attitudes of Parents of Cerebral Palsied Children. Dr. Eugene T. McDonald and Dr. Forrest G. Moyer [3] discussed the necessity of proper development of the attitudes of parents of cerebral palsied children. By indicating some of the sources of improper attitudes, he developed a series of admonitions to be brought to the attention of physicians and other workers with the handicapped child.

The manner in which parents are apprized of the handicap may have a prolonged effect on parental attitudes. Hostility may arise in the parents particularly if the early discussions are carried out in a rushed or hasty visit. The particular implications of the term "mental deficiency" have been found responsible for many misunderstandings. The value of leading the parents into their own establishment of the diagnosis was stressed, using the approach that the diagnosis required time for accurate establishment, often depending more on the rate of progress than on any single examination. It was recommended that parents be assigned some simple training tasks so that they would arrive at their own understanding of the possibility of further development of the child.

Physicians were admonished to remember that occasionally parents need rapid and intensive support, appropriate reading materials, acquaintance with other afflicted families, and referral to local agencies. Long range advance planning is necessary to make the transition to the adolescent period when the patient has outgrown the need for an active treatment program. Failure to carry out adequate planning leads to an unsatisfactory situation when the family is unprepared to face the reality of the long period ahead. Guilt feelings on the part of the parents are to be discouraged by avoiding the suggestion that they are doing an unsatisfactory job at home, that they are neglecting the child, or that they have not carried out instructions properly.

Dr. Meyer A. Perlstein [4] discussed the paper and suggested that Dr. McDonald had highlighted pitfalls which are commonly encountered in this most demanding doctor-patient relationship and suggested that all physicians who undertake this work would be well advised to pay particular attention to these problems.

A Study of the Effect of a Superimposed Respiratory Pattern on the Breathing and Speech of Eight Athetoid Children. Dr. Frank B. Wilson and Dr. Meyer A. Perlstein [4] reported on a six-week test period during which eight children had been subjected to external respiratory support from a device known as the Electro-lung. This apparatus is capable of electrical stimulation of the diaphragm and abdominal muscles alternately.

The eight patients had moderate to severe athetoid cerebral palsy and had been given speech therapy for one year or more prior to the test period. Each had a typical erratic breathing pattern. Prior to the test periods, the patients were studied with regard to their rates of respiration, oxygen consumption, mean tidal air, vital capacity, periodicity of respiration, and ventilation. Tape recordings were made of the subject's reading of a short passage, counting, and the ability to sustain the sound *ah*.

The treatment consisted of twenty-five minutes a day of electrically assisted respiration for a total of

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[3] 227 North 17th Street, Allentown, Pennsylvania.
[4] 4743 North Drake Avenue, Chicago, Illinois.

thirty treatments. Repetitions of the preliminary evaluations were carried out at intervals through the treatment period and also after the completion of the study.

The respiratory rate showed an appreciable decline at the end of the treatment period with a tendency to return toward normal after the daily treatments had been completed. Vital capacity increased an average of 200 cubic centimeters and was maintained. Tidal air measurements indicated no change throughout. Deviations of periodicity of respirations seemed to show some improvement but in no case approached normal. There was no change in the time interval of breathing. In oral counting of numbers, appreciable gains were noted, but the improvement was temporary and was not maintained at the four-week test after the daily treatments had been completed.

The final conclusion was that the Electro-lung appeared to be an effective method for improving breathing and speech of the athetoid subject, although the authors conceded that mean tidal air, vital capacity, and length of sustained phonation were not significantly altered.

Dr. Russell Meyers [5] commented on previous experimental work which indicated that it was possible to alter certain other basic physiological processes by sufficient conditioning, with the implication that longer exposure to the altered respiratory pattern might have had some effect on the trend of rapid return to the pre-test measurements.

Sunday, November 18, 1956

Meprobamate in Cerebral Palsy. Dr. Harriet E. Gillette [6] reported on fifty-one cerebral palsy patients who had received meprobamate. Twenty-three had signs of pyramidal damage, twenty-six had signs of extrapyramidal damage, and two exhibited spasticity with athetosis. Direct physical examinations were supplemented by electromyographic studies before and after medication was instituted. Gradation ranged from one plus (mild) to four plus (severe). The patients were classified in two groups. Those in Group I exhibited pyramidal signs and those in Group II exhibited extrapyramidal signs. In Group I, there was a decrease in spasticity in 72 per cent of the patients, lessening of stretch reflex in 56 per cent, increase in functional range of motion in 40 per cent, and lessening of hyperactivity in 25 per cent. In Group II there was reduction of tension in 50 per cent of the patients, reduction of athetosis in 30 per cent, increased function in 40 per cent, and decrease in emotional disturbance in 60 per cent. In the patients with pyramidal signs, the dosage was 300 milligrams to 1.2 gram with 50 per cent of the patients receiving the drug over a period of four to eight months. The dosage in the patients with extrapyramidal signs ranged from 150 milligrams to 2.4 grams. When, to the examiner's fingers, a measurable alteration was determined in the feel of the muscles during contraction (best described as ductility), the electromyographic tracing also demonstrated change somewhere in the central nervous system which augmented facilitation and reciprocal and voluntary inhibition. Placebos were not given for control effects.

Flexin in Cerebral Palsy. Dr. Margaret Watkins [7] and Dr. Martha Helen Hale [8] reported a study of ninety-eight patients with cerebral palsy (sixty-eight spastic and thirty athetoid). Seventy of the patients received flexin and the remainder a placebo. The evaluation record was kept on all patients and included determination of points of eliciting stretch reflex, active range of motion, passive range of motion, resistance range of motion (three to five pounds) of the biceps, triceps, quadriceps, and hamstrings, bilaterally. The evaluation also included hand skills on a time basis, and testing of diadochokinetic rates before starting the drug, after one week of medication, and after four weeks of medication. There were no significant differences between the experimental and control groups as regards the stretch reflex, range of motion, contractures, hand skills, functional activity, muscle strength, and diadochokinetic rate.

Effects of Reserpine on the Learning Capacity of Cerebral Palsied and Other Brain Damaged Children. Dr. William H. Bradford [9], Dr. Phillip N. Hood, and Dr. Joseph Siebel studied thirty cases of cerebral palsy over a period of one and one-half years in order to determine whether the use of reserpine would affect the learning capacity. The age range was 1.3 to 13.4 years, with the average age 5.5 years. Tests were carried out in which the intelligence quotient and motor quotient were used as criteria and the test was used to evaluate the findings. The latter showed so little difference, in most cases, as to be without significance. Reports of parents and therapists were encouraging as to cooperation and general progress and learning achievement and they deemed the drug highly desirable. Results of the tests of the intelligence quotient and motor quotient revealed no significant difference. The drug alleviated behavior problems but was not completely free of serious side effects.

The Third Scientific Session, held Sunday afternoon, was devoted to a Symposium on Basic Research. The following papers were read:

[5] State University of Iowa Hospitals, Iowa City, Iowa.
[6] 1815 Ponce de Leon Avenue, Atlanta, Georgia.
[7] 3503 Fairmont Street, Dallas, Texas.
[8] 3403 Hall Avenue, Dallas, Texas.
[9] 3714 Fairmount Street, Dallas, Texas.

Behavior and Vulnerability of the Blood-Brain Barrier in the Newborn. Dr. Angel Pentschew [10].

Epidemiological Considerations in Cerebral Palsy. Dr. Leonard T. Kurland [11].

Report of Conference on Asphyxia Neonatorum, Brain Damage, and Impairment of Learning. Dr. William F. Windle [12].

Monday, November 19, 1956

Combined Adductor-Gracilis Tenotomy and Selective Obturator-Nerve Resection for the Correction of Adduction Deformities of the Hips. Dr. Sidney Keats [13] stated that surgery of the lower extremities, if carefully planned, is helpful in cerebral palsy of the spastic type. He advocated a combined adductor-gracilis tenotomy and a selective resection of the obturator nerve for correction of the adduction deformity of the hip. This procedure has been done on thirty-eight patients and thirty-five had gratifying results. The author cautioned that a careful preoperative evaluation is most important and that the operation is contra-indicated when flaccid abductors are present. The average age of the children operated upon was three years and three months. The results were evaluated as to ability to stand, ability to balance and ability to walk.

Adductor Myotomies. Dr. Henry H. Banks [14] and Dr. William T. Green [15] presented a review of their experience with the surgical correction of adduction contracture of the hip in the spastic type of cerebral palsy. The evaluation period extended from 1940 to 1954. During that period seventy-eight patients were operated upon to correct adduction contracture of the hip. Of this group, fifty-four had recently been seen and evaluated. Sufficient data were available from the records to include eleven additional patients in order to determine the end result of this particular surgical procedure. The youngest patient operated upon was one year and four months old and the oldest was fourteen. In addition to the adduction deformity there was a mild to severe degree of flexion deformity of the hip, as well as a tendency toward internal rotation deformity in most of the patients. The authors found it very difficult to assess accurately the strength of the abductor muscles of the hip preoperatively. Abnormalities of the hip joint were frequently noted in these patients. Severe valgus of the femoral neck was commonly observed. In nineteen patients thirteen hips subluxated and ten dislocated preoperatively. The majority of the patients reported in this series had an extended period of conservative therapy prior to surgery, including physical therapy and night-time splinting. The surgical procedure employed consisted of myotomy in which the adductor longus, adductor brevis, the gracilis, and the anterior portion of the adductor magnus were divided. A neurectomy of the anterior branch of the obturator nerve was also done. In analyzing the results, thirty were classified as excellent, thirty-nine as good, twenty-seven as fair, and twenty-six as poor.

Supracondylar Wedge Osteotomies. Dr. Frederick G. Day [16] discussed supracondylar osteotomy to correct fixed flexor contracture of the knee joint in cerebral palsy. It was the author's feeling that this method of surgical correction was particularly helpful in the older patients in whom the contracture had been present for a long period of time and in those patients in whom the deformity recurred following soft-tissue correction. The procedure should be done only in spastic patients and each patient should be tested under anaesthesia in order to determine whether the deformity is due to a fixed contracture or to spasm. If it is due to spasm, bracing and physical therapy are resorted to rather than surgery. In describing the surgical technique of the supracondylar osteotomy, the author stressed the importance of doing the entire procedure subperiosteally in order to prevent displacement. A wedge is cut through the bone with its base on the anterior surface and its apex on the posterior surface of the bone, leaving a small portion of the cortex intact. During the past four years a total of ten operations were done by this method and in most instances the procedure was bilateral. The only complication was a temporary peroneal palsy. In none of the patients was there any significant recurrence of the flexion deformity.

Dr. G. W. N. Eggers [17], in discussing Dr. Day's paper, emphasized that the hamstrings, in addition to being flexors of the knees, are also adductors of the hips and that if the knee is relieved of the flexion

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[13] 311 Lincoln Park, Newark, New Jersey.
[14] 300 Longwood Avenue, Boston, Massachusetts.
[15] 300 Longwood Avenue, Boston, Massachusetts.
[16] 530 Tegler Building, Edmonton, Alberta, Canada.
[17] 2201 Market Street, Galveston, Texas.

contracture, the adductors are less functional. The abduction power in some patients will also improve following surgical correction of the flexion contracture at the knee. He stated that he had had no experience in doing wedge osteotomies to correct fixed flexion contracture at the knee, but had utilized transplantation of the hamstring tendons to the femoral condyles combined with a division of the patellar retinacula to correct this deformity.

Dr. Caroll M. Silver [18] agreed with Dr. Day in that a supracondylar osteotomy of the femur is indicated if the soft-tissue contracture is irreversible and will not respond to a soft-tissue release. He also agreed with Dr. Banks, Dr. Green, and Dr. Keats in advocating an adductor tenotomy and sectioning of the anterior branch of the obturator nerve to correct adduction contracture of the hips. He strongly urged that if the contracture of the hips was severe in addition to these procedures the posterior branch of the obturator nerve should be crushed.

Dr. Kenneth B. Jacques [19] agreed with Dr. Banks and Dr. Green on correction of the adduction contracture at the hips. He stated that he had had no experience with wedge osteotomies at the knee to correct flexion contractures, but advised lengthening of the hamstrings and a capsulotomy of the knee. Occasionally he found it necessary to lengthen the gastrocnemius.

The President for the ensuing year is Nicholson J. Eastman, M.D., of Baltimore, Maryland. Officers elected at the meeting are:

President-Elect: William T. Green, M.D., Boston, Massachusetts;

Secretary-Treasurer: Raymond R. Rembolt, M.D., Iowa City, Iowa.

[18] 225 Waterman Street, Providence, Rhode Island.
[19] 3875 Wilshire Boulevard, Los Angeles, California.

NORTH CAROLINA ORTHOPAEDIC ASSOCIATION

The Annual Meeting of the North Carolina Orthopaedic Association was held at Duke University School of Medicine on October 19 to 22, 1956. Dr. E. I. Bugg, Jr., was in the chair.

Among the formal presentations were the following:

Cervical Nerve-Root Compression. Dr. Guy Odom [1] emphasized that a nucleus pulposus in the cervical region is about one-tenth the size of a lumbar nucleus pulposus. Of 205 cases of nerve-root compression, he had found that 148 were caused by unilateral ruptured cervical discs and thirty-four by bone spurs. The roentgenograms of several patients in this group showed a narrow space between the fifth and sixth cervical vertebrae, but a soft protrusion of the nucleus pulposus was actually present at the space between the sixth and seventh cervical vertebrae, and this was evident on the myelogram. A preoperative differentiation between ruptured disc and bone spur could not be made with certainty, even with clinical and myelographic examination. Cervical spondylosis he considered the most common cause of cervical myelopathy. The changes include degeneration of the intervertebral disc with subsequent calcification and a posterior ridge which gradually narrows the spinal canal. The new bone may cause vascular changes involving the anterior spinal artery and vein, place tension on the dentate ligaments, and cause peripheral motor changes. There may be few early peripheral sensory changes. The differential diagnosis includes amyotrophic lateral sclerosis, subacute atrophy of the spinal cord, and other similar neurological conditions. A myelogram may show considerable narrowing of the canal with the central portion unfilled. It is extremely important to diagnose this condition before surgery so that the surgeon can warn the anaesthetist not to extend the head and neck during intubation. He recommended that a myelogram be done only for differential diagnosis and only if the surgeon plans to operate.

The results following removal of ruptured discs were estimated to be good in 90 per cent of the patients. If spurs were present there were good results in about 70 per cent of the patients. Because of the small size of the nucleus pulposus, the recurrence rate in the cervical region was 1 per cent or less.

Surgery for cervical spondylosis included: (1) Removal of three laminar arches and (2) opening of the dura and section of the dentate ligaments. No effort was made to remove the ridge along the posterior vertebral bodies.

Temporomandibular Joint Syndrome: Treatment. Dr. Nicholas G. Georgiade [2] pointed out that the common causes of the temporomandibular joint syndrome are usually malocclusion, traumatic dis-

[1] Department of Neurosurgery, Duke University School of Medicine.
[2] Department of Plastic, Maxillofacial, and Oral Surgery, Duke University School of Medicine.

turbances with resultant meniscitis, dislocation of the meniscus, condylar fractures, rheumatoid arthritis, osteo-arthritis, and fibrosis of the temporomandibular joint area.

In the mild cases the major symptom was clicking, and the treatment was correction of malocclusion.

In cases of moderate severity, there was clicking with occasional locking and swelling in the temporomandibular joint region associated with pain on opening the mouth. Treatment in the more acute phases includes local injection with 2 per cent xylocaine, local injection with hydrocortisone acetate, and maintaining the patient on a soft diet. If these measures fail, wiring of the jaws to maintain a closed bite for several weeks could be tried. If conservative therapy fails, excision of the meniscus is indicated.

Condylar fractures of the mandible necessitate complete roentgenographic study. Planigrams are made in order to outline the condyle clearly and also a 45-degree angle view through the opposite coronoid notch is made. Conservative treatment for most condylar fractures is usually indicated. For the badly displaced condylar fractures with accompanying malocclusion, open reduction and wire fixation is recommended.

Fundamental Problems and Complications in Pediatric Anesthesia. Dr. C. R. Stephens [3] indicated that the commonest cause of death in the pediatric patient is anoxaemia. Lack of oxygen during anaesthesia may be precipitated by (1) inadequate concentrations of oxygen in the inhaled gases, (2) breath-holding, obstruction of a portion of the respiratory tract, or laryngospasm secondary to inadequate premedication, (3) drugs which depress respiration, (4) low hemoglobin or excessive blood loss, and (5) hyperpyrexia.

Chest Wall Deformities. Dr. W. C. Sealey.[4]

Peripheral Nerve Pain: Four Difficult Problems. Dr. Barnes Woodhall [5] distinguished between major causalgia, which responds to diagnostic sympathetic block and to sympathectomy, and the minor causalgias or painful dysaesthesia. Pain in a nerve injury results from injury of the sensory axons. Microscopic study of an amputation neuroma may show incomplete regeneration of axons, a foreign-body reaction to a suture line or scar, infection, and bone fragments. He pointed out that the C fibers are poorly myelinated and may be the cause of the dysaesthesia. He presented four patients with representative pain syndromes.

Indications for Thoracolumbar Sympathectomy. Dr. Keith Grimson [6] discussed the middle-aged person with claudication and raised the question of adjusting to the problem by low-fat and low-cholesterol diets, limited activity, and surgery which includes homografting and sympathectomy. If sympathectomy is done, the surgeon can feel the aorta and determine the necessity for homografting at a later time. Following sympathectomy, the femoral pulse was palpable in five out of thirty patients. Dr. Grimson emphasized the necessity for using arterial homografts following acute trauma, such as that seen with posterior dislocation of the tibia with circulatory impairment. Postoperatively, plaster immobilization should be used in order to hold the joint in extension. This is important when grafts are placed about the groin or the popliteal regions.

Thrombo-Embolic Disease. Dr. W. W. Shingleton [7] declared that venography has been a great help in diagnosing certain conditions associated with thrombosis of the venous system. Anticoagulation for venous thrombosis was good, except when there are large wounds, liver disease, or suppurative pelvic phlebitis. In treating the postphlebitic leg, Dr. Shingleton emphasized the (1) treatment of infection, (2) local treatment of ulcers, (3) ligation or stripping of certain veins, and (4) medial compartment dissections when the disease is persistent.

Carcinoma of the Prostate. Dr. E. P. Alyea [8] declared that 70 per cent of the patients with metastatic carcinoma of the prostate show an elevated serum acid phosphatase. It has become of so much importance that it is generally believed the prognosis in a patient with an elevated serum acid phosphatase and without the evidence of obvious metastases is just as bad as that in the patient with bone metastases seen roentgenographically. Another diagnostic aid is the study of the bone marrow; 58 per cent of the patients who have sternal pain and marked oedema had the malignant cells in the bone marrow obtained at sternal aspiration. Needle biopsy, either through the perineum or directly through the rectum into the prostate is now frequently used as an aid to a definite diagnosis. Seven cases of paraplegia from carcinoma of the prostate were presented. Three of these patients showed sensory and motor recovery within a period of two weeks following treatment. These three were paraplegic for ten days or less. All patients who were paraplegic for more than ten days had no return of sensation or motor power. It is thought, therefore, that if hormonal therapy is going to be beneficial in these patients with paraplegia from metastatic carcinoma, they must be treated within the first two weeks of its onset.

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[4] Department of Thoracic Surgery, Duke University School of Medicine.
[5] Department of Neurosurgery, Duke University School of Medicine.
[6] Department of Surgery, Duke University School of Medicine.
[7] Department of Surgery, Duke University School of Medicine.
[8] Department of Urology, Duke University School of Medicine.

Current Status of Specific Drug Therapy for Fungus Infections. Dr. Norman F. Conant [9] pointed out that the disease actinomycosis must be differentiated into two clinical types based on the etiological agent: actinomycosis caused by the anaerobic *Actinomyces bovis* which is treated with penicillin, and nocardiosis caused by a species of Nocardia which is treated with sulfonamides.

The clinical entity maduromycosis (Madura foot) may be caused by higher filamentous fungi or by a species of aerobic actinomycetes, Nocardia. There is no specific treatment if the higher filamentous fungi are the cause of this disease whereas those infections caused by species of Nocardia can usually be treated successfully with sulfonamides.

Blastomycosis may involve the skin, bones, or lungs. Dihydroxystilbamidine is the drug of choice for this infection; it has been successfully used regardless of the organs involved.

Cryptococcosis of the skin, bones, or lungs will respond to sulfonamide therapy, but the meningeal form of the disease is resistant to all known drugs.

The diseases mentioned can be diagnosed accurately only if laboratory facilities are available. Since they simulate each other as well as tuberculosis and a variety of malignant neoplasms, cultural studies and histological preparations must be obtained for a definitive diagnosis.

Studies on the Metabolic Defect of Gout. Dr. James B. Wyngaarden [10] stated that the primary metabolic defect leading to accumulation of uric acid in the patient with gout is not yet defined. Laboratory studies have not demonstrated any specific disorder of renal excretion of uric acid in gouty persons. Limited uricolysis does occur in man, despite the absence of uricase, but there is no substantial evidence to suggest a defect of uricolysis in gout. Studies involving the measurement of the rate and extent of conversion of N^{15}-glycine into uric acid (Stetten) have demonstrated overproduction of uric acid in some but not all gouty persons. That this overproduction probably results from excessive cleavage of newly formed nucleotides, and subsequent oxidation of the purine bases to uric acid, is suggested from studies of the isotope labeling patterns found in urinary xanthine, hypoxanthine, adenine, guanine, and 7-methylguanine.

Clinical sessions followed.

Dr. Walter Hunt was elected President for 1957.

[9] Department of Mycology, Duke University School of Medicine.
[10] Department of Medicine, Duke University School of Medicine.

ARTHRITIS AND RHEUMATISM

The American Rheumatism Association has announced the forthcoming publication of a new medical journal *Arthritis and Rheumatism*—the official journal of the American Rheumatism Association. The new journal will appear bimonthly, starting with the January-February issue of 1958. The Association has announced that Dr. William S. Clark, Associate Professor of Medicine at Western Reserve University School of Medicine and well known for his studies in rheumatic disease is the Editor of the new publication. The Association's Publication Committee is composed of Dr. Richard H. Freyberg, Dr. William H. Kammerer, Dr. John Lansbury, Dr. Charles Ragan, and Dr. Charles L. Short. The Editorial Board will be announced subsequently.

The Journal will cover the field of connective-tissue disorders, in particular rheumatoid arthritis, osteoarthritis, rheumatic fever, gout, the so-called collagen diseases, and non-articular rheumatism. Editorially it is hoped to achieve an optimum balance between original articles relating clinical experience and those which report pertinent developments in the basic sciences, such as immunology, biochemistry, pathology, and pharmacology. In addition to original and review articles, special departments will include news and notices, correspondence, editorials, progress reports, and book reviews. The contents of the Journal should interest not only the specialist in rheumatic diseases but also the orthopaedic surgeon, internist, research worker, and all practitioners with a special interest in these diseases.

No orthopaedic surgeon interested in teaching orthopaedic surgery, engaged in research, or engaged in the treatment of any of the aspects of connective-tissue disorders can afford not to be familiar with this important new periodical relating to clinical practice and research and to pertinent studies in the basic sciences.

STERLING BUNNELL
1882-1957

Dr. Sterling Bunnell, beloved surgeon, world renowned for his epoch-making contributions to the surgery of the hand, died at his home in San Francisco on August 20. Although active in his many fields of interest almost to the last (he had attended the 1957 Annual Meeting of The American Orthopaedic Association in June and that of The American Academy of Orthopaedic Surgeons in January) he had not been in good health for some months.

A memorial tribute will appear in a subsequent issue of *The Journal*.

CHARLES D. NAPIER
1864-1957

Dr. Charles D. Napier was born January 31, 1864, the son of Alexander D. Napier of Brooklyn, New York, and Laura Dwight of Richmond, Massachusetts. He graduated from Polytechnic Preparatory School of Brooklyn in the class of 1881 and from Yale in 1885. While at Yale, he was a member of the Psi Upsilon Fraternity. He graduated from the College of Physicians and Surgeons in New York City in 1890 and served as intern at St. Mary's Hospital in Brooklyn. After the internship, he evinced an interest in orthopaedic surgery and became a clinical assistant at the Hospital for the Ruptured and Crippled. His hospital staff appointments, contrary to the custom of the era, were solely in orthopaedic surgery. He became Associate Orthopaedic Surgeon at St. Mary's Hospital and at the Methodist Hospital in Brooklyn. He joined the staff of the Long Island College Hospital and Medical School and attained the rank of Clinical Professor of Orthopaedic Surgery at the College.

In 1899, he published *Diagnosis of Hip Disease*, in 1906, *Principles of Mechanical Support*, and in 1915, *Preventive Orthopaedics in Infancy and Children*. There is a newspaper clipping from the *Brooklyn Eagle* which states that, in 1933, when Dr. Napier was Chief of Surgery at the House of St. Giles the Cripple, he conducted a posture clinic and invited two thousand students at Girls Commercial High School to be examined for curvature of the spine. As late as 1955, Dr. Napier was still occasionally found in the clinic at St. Giles.

He was a man of firm convictions and lasting loyalties. He was fiercely proud of his Scotch ancestry and an ardent member of St. Andrews' Club of New York. In 1917 Dr. Napier served with the American Expeditionary Forces in France with the rank of Major in the Medical Corps. Some of his happiest days were spent at Sag Harbor, where he was a devotee of yachting. In 1923, he was Commodore of the Sag Harbor Yacht Club.

Dr. Napier was fond of attending Class Day at New Haven. In 1955, when three members of his class of 1885 were still alive in the metropolitan area of New York, one of them suggested that they hold their annual meeting at the Yale Club in New York and receive the results of the Yale-Harvard baseball game there. Dr. Napier refused to hear of this. He attended the reunion at New Haven and after the alumni luncheon, walked with the parade to the ball field and returned to Brooklyn alone. This at ninety-one and a half years!

At the time of his death, February 18, 1957, in his ninety-fourth year, he was a member of the American Medical Association, a Fellow of the American College of Surgeons, a member of The American Academy of Orthopaedic Surgeons, The American Orthopaedic Association, and the Brooklyn Surgical Society. He was also consulting orthopaedic surgeon at the House of St. Giles the Cripple, St. John's Episcopal Hospital, St. Mary's Hospital, Kings County Hospital Center, Long Island College Hospital, Caledonian Hospital, Wyckoff Heights Hospital, all in Brooklyn, and Southampton Hospital in Suffolk County, Long Island, New York.

R. F. W.

News Notes

The next Annual Meeting of **The American Orthopaedic Association** will be held jointly with **The British Orthopaedic Association** at The Shoreham, Washington, D. C., May 11 to 16, 1958.

The next Annual Meeting of **The American Academy of Orthopaedic Surgeons** will be held at the Waldorf-Astoria, New York City, February 1 through 6, 1958.

The Thirteenth Annual Meeting of the **American Society for Surgery of the Hand** will be held at the Waldorf-Astoria, New York City, on Friday and Saturday, January 31 and February 1, 1958, under the Presidency of Dr. J. Edward Flynn.

The Sixty-Fourth Annual Convention of the **Association of Military Surgeons** of the United States will be held in the Hotel Statler, Washington, D. C., October 28 to 30, 1957. The theme of this meeting is "Professional Excellence — The Criterion of Military Medicine."

At a recent meeting of the **Washington Orthopaedic Club,** the following officers were elected for the ensuing year:

President: John P. Adams, M.D.;
Vice-President: Sanford H. Eisenberg, M.D.;
Secretary-Treasurer: Allan M. McKelvie, 1801 K Street, N.W., Washington, D. C.

The **Easter Seal Research Foundation** of the **National Society for Crippled Children and Adults** provides grants-in-aid for investigation concerned with the prevention and treatment of physical and associated disabilities and the rehabilitation of the physically handicapped. Disabilities may be congenital or may result from accident or illness; accident prevention, *per se,* is outside the scope of the Foundation's research interest. The Foundation invites applications for grants-in-aid. Applications filed between September 1 and March 31 are reviewed in June; applications filed between April 1 and August 31 are reviewed in November. Awards are announced during the months of June and November. For further information, interested persons should write the Easter Seal Research Foundation, the National Society for Crippled Children and Adults, Inc., 11 South LaSalle Street, Chicago 3, Illinois.

The **National Foundation for Infantile Paralysis** invites applications for post-doctoral fellowships in research, academic medicine, or in the clinical fields of psychiatry, rehabilitation, orthopaedics, the management of poliomyelitis, and preventive medicine. December 1, 1957, is the current deadline for applications. Financial support of the Fellow varies according to his previous education, his professional experience, marital status, and number of dependents.

Orthopaedic fellowships for advanced training in teaching or research or both are available from the National Foundation for Infantile Paralysis for those physicians who have completed the requirements for certification by the American Board of Orthopaedic Surgery or who have equivalent training. The age limit is thirty-six. Awards are made for a period of one year and are subject to renewal. All applicants must be citizens of the United States. Financial benefits, in addition to the compensation to the institution, vary from $4,500 to $6,000. Under unusual circumstances, higher stipends may be permitted.

In the management of poliomyelitis, awards are made to licensed physicians who wish to acquire a knowledge of the various aspects of the total care of poliomyelitic patients. A fellowship for one year for full-time study may be undertaken at any institution having suitable facilities and staff for this type of program. One year of internship is required. Financial benefits are $300.00 or $350.00 a month depending on marital status with $25.00 additional for each dependent child. Compensation to the institution is also arranged.

Applications received before December 1, 1957, will be considered in February, and applications received before March 1, 1958, will be considered in May. All awards are made upon recommendation of the National Foundation Clinical Fellowship Committee. For information write: Division of Professional Education, National Foundation for Infantile Paralysis, 301 East 42nd Street, New York 17, N. Y.

Book Reviews

GOUT. John H. Talbott, M.D. New York, Grune and Stratton, 1957. $6.75.

In the preface to this new monograph on gout, the author explains that in completely rewriting an earlier version he is motivated "by a desire to arouse physicians to a greater interest in the recognition of gouty arthritis," as well as to include recent advances in the knowledge and treatment of the disease. The sections dealing with the clinical aspects of gout are well written and authoritative, reflecting the author's sustained interest and broad experience in the management of gout. Unfortunately, the introductory sections, comprising about one-third of the text, are not of this quality; the reader is obliged to endure much that is dull, obscure, and even irrelevant. The section on history could have been brightened by the inclusion of some of the earlier clinical descriptions of the disease and by the omission of literary quotations alluding to gout, ranging from the Bible to Gilbert and Sullivan. The section devoted to definition does not clearly define the disease or the terms used. For example: "(2) Upon the appearance of *acute gouty arthritis* (Plate I) its expositive nature drives the afflicted person to his doctor for advice." It is in this section that the term *intercritical period*, meaning the period between attacks of gouty arthritis, is introduced. It is to be hoped that this term, and the synonymous term *prophylactic period*, do not gain wide acceptance. The section on etiology is summarized in the following sentence: "The metabolic defect, then, is a partial reversion to the normal situation in birds and reptiles, namely a significant *uricotelic* component in a predominantly *ureotelic* species." Since the author does not explain the normal situation in birds and reptiles until a later section and since his two italicized words are nowhere defined, the average reader will have to strain his deductive powers in order to decipher this message. Moreover, the section on the pharmacology of colchicine, although including a rather lengthy report (dated 1820) of its use in a case of inflammatory fever in a horse and a reference to its effect on mitosis in plants, neglects to mention except by inference its extraordinary specificity in acute gout.

Much of the material which is treated in detail in the clinical sections of the monograph is also given space in the introductory sections. Better organization of the subject matter would have avoided repetition.

Nevertheless, Dr. Talbott's monograph accomplishes its purpose in presenting a thorough account of the clinical aspects and the management of gout. In this it is aided by an excellent choice of illustrations in color and by a considerable number of carefully selected reproductions of roentgenograms. A set of diagrams depicting the course of the disease and the effect upon it of various drugs also enhances the text. The description of the kidney complications of gout, with their peculiarly protracted course, will doubtless be enlightening to many readers.

There are two aspects of gout which are given special emphasis by the author and which may therefore be summarized here. These are (1) that the diagnosis of gout is often missed for years after the onset of joint symptoms and (2) that the modern treatment of gout can reduce to insignificant proportions the amount of disability from the disease. Gout is not an uncommon disorder — it is estimated that there are 300,000 cases in the United States—and it should always be considered in the differential diagnosis of joint disease, most particularly in adult males. According to the author, the most helpful diagnostic features are the sudden and acute nature of gouty arthritis and a history of previous similar attacks without permanent joint deformity. An elevated serum uric acid level (above six milligrams per 100 milliliters) is an almost invariable confirmatory finding if salicylates or other uricosuric agents have not been administered. A positive family history of gout or a past history of renal calculi should raise the index of suspicion. A prompt subsidence of pain and inflammation after full doses of colchicine have been given is strong confirmatory evidence. Urate tophi and the typical changes in affected joints as seen roentgenographically are pathognomonic but are not to be expected in early gout.

In treatment of the acute attack, colchicine maintains its place as the only truly specific drug. It is also the most effective and the safest. Failure to control symptoms with colchicine is usually attributable to insufficient or delayed dosage. Phenylbutazone is also extremely effective in acute gout, but because of its toxicity should be reserved for selected cases. ACTH and the adrenal corticosteroids, according to the author, are slower and less certain in their actions. In the management of chronic gouty arthritis and the period between acute attacks, Dr. Talbott has long been an advocate of the continuous use of small doses of colchicine; he has convincing data to show that this regimen sharply reduces the number and severity of attacks. Since 1950, the introduction of probenecid (Benemid) a potent uricosuric agent, has added another important tool to the management of gout. By increasing the urinary excretion of urates, probenecid reduces the size of the "miscible pool" of urates in the tissues, causes a sharp lowering in the serum uric acid level, reduces the frequency and severity of attacks of gouty arthritis, diminishes the size of subcutaneous tophi, and permits healing of the osseous lesions of gout. For almost all of his patients the author recommends continuous treatment with both colchicine and probenecid and states that after an initial period of stabilization "a majority of patients, irrespective of the severity of the disease, average less than one day per year incapacity because of acute arthritis" on this regimen. Although other investigators have reported the eventual abolition of attacks of gout with probenecid treatment alone, Dr. Talbott takes a strong stand on this point: "We do

not have any patients who have been on Benemid only, nor do we propose to obtain such clinical data since the results of colchicine and Benemid are to us definitive." Whether or not this opinion will be justified by further experience, it is apparent that probenecid has radically altered the natural history and the prognosis of gout. It will behoove physicians to become more familiar with the diagnostic criteria and the details of treatment of gouty arthritis.

Reed Harwood, M.D.

INJURIES OF THE HAND. Ronald Furlong, F.R.C.S. Boston, Little, Brown and Company, 1957. $9.00.

This English text, or, as the author prefers to call it, instructional manual on hand injuries, was written for the young surgeon making his first contact with the specialty. Following a brief anatomical résumé, each tissue, skin, tendon, nerve, and bone is given methodical treatment as to injury, diagnosis, repair, and after-treatment. Other chapters cover technical considerations, infections, and post-traumatic disabilities.

Throughout, the approach is conservative and in some instances quite in contrast to the more aggressive American teaching. The treatment methods employed, with few variations, more or less parallel our own.

The illustrations, almost without exception, are actual photographs well chosen to complement the subject matter, and the text, in easy English style, and with a touch of humor here and there, is most acceptable. The book is practical and concise and should well serve the purpose for which it was written.

Lot D. Howard, M.D.

ELECTRODIAGNOSIS AND ELECTROMYOGRAPHY. Edited by Sidney Licht, M.D. New Haven, Elizabeth Licht, 1956. $10.00.

This book is unique in comprehensively presenting both electrodiagnosis and electromyography. Dr. Licht and the eleven contributors, all physicians, have given us an excellent text as well as reference book on these increasingly important subjects. Sketches and descriptions demarcating dermatomes and motor points are well presented. Chronaxia and strength duration curve descriptions are coupled with their clinical applications.

After a review of the history of neuromuscular physiology, all types of strength duration curves taken from case records are illustrated and described. Similarly, virtually all types of electromyographic tracings are analyzed. Illustrations are clear-cut and portray both normal and abnormal potentials. Abundant applications in clinical medicine are recorded including the myasthenias, myotonia, poliomyelitis, hysterical paralysis, and peripheral nerve injuries.

The technique for identifying nerves in the operating room is included.

Brief chapters on the subjects of electroencephalography and electroretinography add to the comprehensive coverage characteristic of this book.

In general, the only time that the strength duration curve is more accurate than the electromyogram is during the first two weeks following nerve injury. Whereas the strength duration curve tests only part of the nerve root, the electromyogram records both the anterior and posterior primary divisions of the nerve root.

This book can be enthusiastically recommended to all physicians concerned with neurogenic and myogenic entities. Orthopaedic surgeons will find this an exceedingly useful reference book.

J. Vernon Luck, M.D.

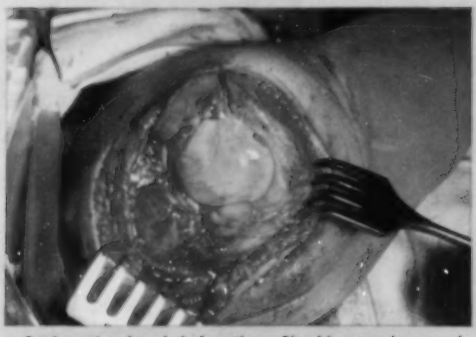
RECHERCHES SUR LA CONSTITUTION DE L'OS ADULTE. J. Vincent. Bruxelles, Edition Arscia, n.d.

Primarily, this dissertation reports the work of the author on compact bone of adult dogs, studied by means of microradiography, classical histology, and autoradiography with calcium 45 and sulphur 35. Also studied in less detail are specimens of spongiosa from the dogs and a few specimens of compact human bone. The author presents fundamental data on the development and remodeling of Haversian systems, nearly all of the data being morphological rather than physiochemical. His experimental material, illustrated by photomicrographs, microradiographs, and autoradiographs of the same high-powered fields, is very instructive both as regards content and technique. The studies, performed in the laboratory of LaCroix, follow the same productive investigative methods characteristic of his school: a combination of classical histology and new methods of morphological study developed only within the last decade. While no refinements of published techniques are reported in this small monograph, the literature is reviewed in detail and the author is very careful to avoid doctrinaire interpretations of the data.

This small publication, therefore, while representing a fulfillment of requirements for an advanced degree, combines some of the features of original investigation with those of a review. Since the subject, the remodeling of bone in the adult, is so important at this time because of the relationship between the remodeling and the internal deposition of bone-seeking radioisotopes, this work should receive widespread attention. For those who are interested in bone physiology and morphology, much of interest will be found in this short volume.

Jonathan Cohen, M.D.

2. Skin draped. Saber incision outlined at acromion.



3. Acromion denuded of cartilage. Shoulder capsule opened.

4. Acromial process of the scapula osteotomized.
Turn page for other color illustrations of surgery.

SHOULDER ARTHRODESIS:
1. Radiograph (A-P view). Shoulder prior to surgery. Note atrophy of muscle and soft tissue, and relaxation of joint.

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5. In succession: Flap is osteotomized in head of humerus; cartilage is denuded from head of humerus, which is joined to acromial process.

6. Acromial process now in head of humerus.

7. Cuff of shoulder capsule reefed to scapula.

8. Wound closed and prefitted cast applied.

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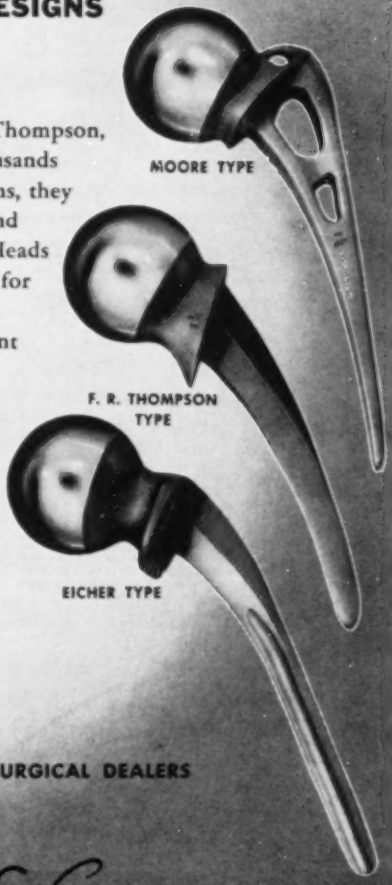

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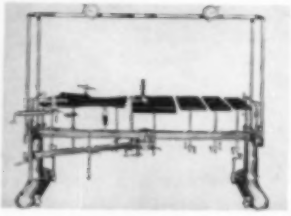

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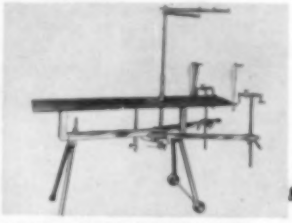

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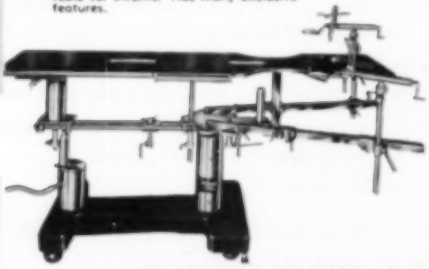

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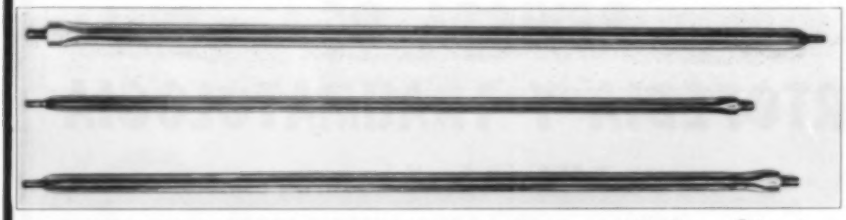

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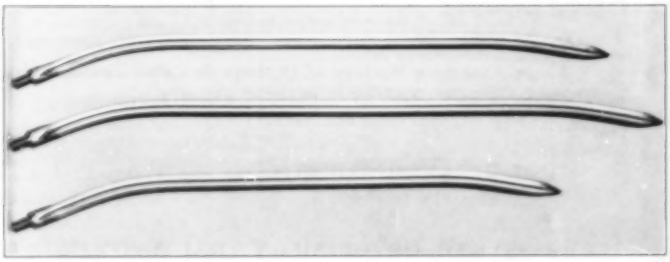

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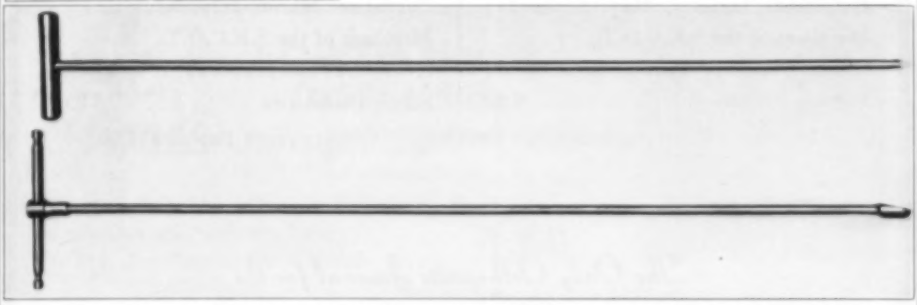

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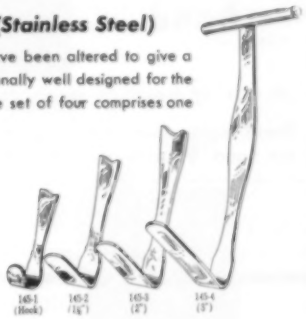

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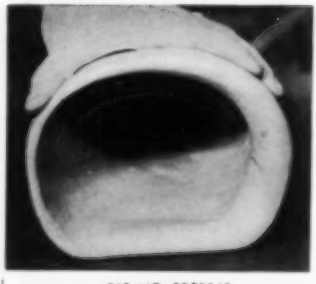

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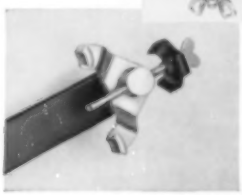

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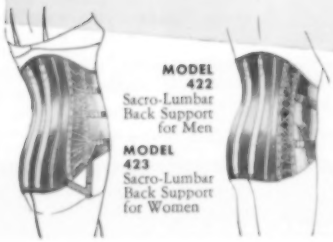

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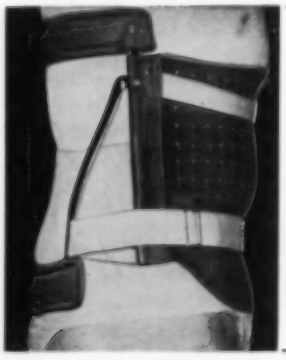

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